Title	Inter-sectoral and Inter-temporal Diversification of Agricultural Disaster Risk : Equilibrium Analysis of Risk Sharing Puzzle and the Role of Government(Dissertation_全文)
Author(s)	Ye, Tao
Citation	Kyoto University (京都大学)
Issue Date	2009-11-24
URL	http://dx.doi.org/10.14989/doctor.k15002
Right	
Type	Thesis or Dissertation
Textversion	author

Inter-sectoral and Inter-temporal Diversification of Agricultural Disaster Risk:

Equilibrium Analysis of Risk Sharing Puzzle and the Role of Government

Tao Ye

September, 2009

Inter-sectoral and Inter-temporal Diversification of Agricultural Disaster Risk: Equilibrium Analysis of Risk Sharing Puzzle and the Role of Government

Tao Ye

Supervised by

Prof. Norio Okada

Kyoto University

September, 2009

Acknowledgement

This thesis contains my work during the past three years in Kyoto University. It is a miracle for me as three years ago I knew almost nothing about economics. Today, however, I dare to say that I know something about the financial management of disaster risk, although the area illuminated by the light of wisdom is still so limited. It is the biggest progress and the most important step to change from 0 to 1, although steps from 2 to 99 are much more challenging. By this moment, I would like to appreciate people who have ever helped me to make this first step and taught me how to keep my pace to my final goal.

First of all, I would like to acknowledge my supervisor, Prof. Norio Okada, the present director of Disaster Prevention Research Institute of Kyoto University. Without Prof. Okada, my appearance and experience in Kyoto University could have been merely a legend in my dreams. He is a great researcher who has mastered the art of management and planning, especially in coping with disaster risks. His kindness to me is far beyond the enlightening discussions, critical questions, and serious challenges that have ever allowed this thesis to come into existence. He has guided me to the path of perceiving the essence beyond the appearance and granted me the enthusiasm and courage to continue my life as a researcher.

My heartfelt thanks go to my tutor, Dr. Muneta Yokomatsu, who has ever given me my fist lessons in economics. He has thought me the way of thinking in economics. He also has offered me the most fundamental but strict training in developing economic models. From him, I have also learned the true essence of diligence, determination, and perseverance that a young researcher should definitely follow. Meanwhile, he is such a gentle and nice tutor who has always made sound considerations on my matters even more than me. If I could ever become a teacher in universities who is supposed to give advice to graduate students, the way that Dr. Yokomatsu has guided me is exactly what I should follow.

Special thanks go to professors and visiting professors of Kyoto University who have helped, suggested, and challenged me. They are Prof. Kiyoshi Kobayashi, Prof. Hirokazu Tatano, Prof. Katsuya Yamori, Prof. Kaoru Takara, Dr. Michinori Hatayama, and Dr. Yukiko Takeuchi from DPRI of KU; Prof. Bijayanand Misra from School of Planning and Architecture (India); Dr. Aniello Amendolla from International Institute for Applied Systems Analysis (Austria); Prof. Liping Fang from Ryerson University (Canada); Prof. Keith Hipel from University of Waterloo (Canada); Prof. Chennat Gopalakrishnan from University of Hawaii at Manoa (USA); and Dr. Young-choel Lee from Hope Institute (Korea).

I owe a lot to Prof. Peijun Shi, vice president of Beijing Normal University (China), as well as my former supervisor when I was a master candidate there. Nevertheless, it seems that I am going to owe him more and more, since I am going to return to Beijing Normal University and start my career as a young researcher in his group. My present and future efforts can hardly offset his grace and generosity to me. Thanks also go to my colleagues in Prof. Shi's group for their kind efforts in the long-lasting and exhausting field work in Hunan Province in the summer of 2008. They are Dr. Wendong Nie, Dr. Ming Wang, Mr. Zhiguo Zhao, Ms. Jing Liu, Mr. Fei He, Ms. Juan Du, Mr. Hong Cheng, Ms. Meiqin Zhou, and Mr. Shiqiang Du.

Collective and individual acknowledgements will also be delivered to my colleagues at Kyoto University. I should thank all other students in this internationalized Okada Lab who have shared their courage and happiness with me together. They are Megumi Sugimoto, Yoko Matsuda, Kazuki Yoshioka, Ryusuke Ikeuchi, Tsuyoshi Toda, Itaru Endo, Yuji Ogawa, Yu Matsubara, Miyuki Hayashi, Yuki Fukushima from Japan, Suman Ranjan Sensarma and Samaddar Subhajyoti from India; Saut Sagala and Risye Dwiyani from Indonesia; Jong-il Na and Kongwon Lee from Korea; Roshan Bhakta Bhandari from Nepal; Wei Xu, Yuling Liu, Shuoqi Li and Yingying Sun from China. Among them, I must specially thank Dr. Wei Xu, who helped me assimilate in Okada Lab when I came to Kyoto when I knew nothing about Japanese, and also who I am going to work with after becoming a young researcher in Beijing Normal University.

I am also indebted to secretaries at the research center who have enabled me to stay far away from miscellaneous errands to concentrate on and enjoy my own research. They are Ms. Michiko Yoshioka, Ms. Akiko Endo, Ms. Keiko Inoue, Ms. Chisato Sano, and Ms. Yumie Hayashi.

Gratitude goes to my dear parents and other family members, for their understanding and generous support. My dear friends in both Japan and China, especially Jessica Pan and Berry Bear, are appreciated here for their mercy, patience, and encouragement which helped me to survive from the hardest hours I endured.

Finally, I would like to thank all those who have been important to the success of my thesis and express my sincere apology that I have not mentioned name by name.

Abstract

Disaster risks cannot be efficiently financed if the risk itself cannot be well understood, correctly modeled, and actuarially priced. It is also difficult if the market for sharing the risk operates inefficiently and the capacity of risk-pooling is limited. This thesis aims at exploring the factors that create obstacles for efficient risk sharing among economic sectors and risk diversification across time periods. It is also to provide policy implications to help overcome those obstacles so that the efficiency of insurance market in allocating resources and risk-bearing can be improved. It follows the viewpoint of development economics that risk diversification must be put into the context of economic development and in the process of resources allocation for production and wealth redistribution for consumption. Dual-economy structure with equilibrium analysis as well as collective risk theorem is the key approach employed in this work.

The major focus of this thesis is about the diversification of agricultural disaster risk. The inter-sectoral and inter-temporal diversification provides an alternative perspective on risk sharing in dual-economy structure other than classical inter-regional issues. Starting from the most common government policies that make direct fiscal transfers from tax-payers to rural producers, this thesis presents three models in similar structures to address the labor allocation and risk diversification problem between agriculture sector and manufactory sectors. Disaster risk is assumed to be borne mainly by the agriculture sector and risk sharing approaches, either centralized or decentralized, are discussed. The model structure is truly "inter-sectoral" diversification because damaged production not only influences the income of producers but also determines how many products are available for consumption in the market. In this sense, both producers and consumers of agriculture product are bearing the risk. Regarding the inter-sectoral aspect of disaster risk diversification, this thesis mainly addresses the questions as below:

1) Should government conduct inter-sectoral fiscal transfer to rural producers to control the rural-to-urban migration, provided the fact that disasters may strike both sectors and interrupt production process, that rural residents are potentially able to move to work in the urban sector seasonally, and that all consumers have to pay transaction costs for shipping the goods for consumption?

2) Can the popular government-subsidized crop insurance program achieve its desirable goal that with the direct subsidy to insurance premium paid by producers, each producer may produce more from his/her land, and more resources are attracted to be engaged in agriculture production?

3) What is the effect of government policies regarding market grain supply in diversifying the risk inter-temporally and re-allocation between rural producers and urban consumers?

4) What are the key constraints for individuals and the insurance market to implement buffer-stock strategy for diversifying the risk inter-temporally? How can a government use financial as well as policy instruments to enhance the capacity?

Major findings of the models imply that

1) Whether the migration behavior should be controlled or not depends on the size of transaction costs for migration. If the costs for migration are low, then it is necessary for the government to control the migration, or vice versa. The first-best disaster insurance market is efficient in allocating both resources and risk-bearing in the economy for all levels of labor mobility. Goods tradability, however, induces externality and undermines the efficiency of the disaster insurance market.

2) One reasonable explanation for the failure of crop disaster insurance market is that urban consumers of agriculture product are bearing much more disaster risks than rural producers that destroy the production in the agriculture sector. In this sense, they are more in need of insurance coverage than producers. If it follows that in the economy rural producers get higher revenue of selling agriculture product when the yield is worse, premium subsidy may probably reduce the output at the individual level, but it definitely attracts more labor to work in the agriculture sector.

3) Grain policies that reduce the cross-period variation of market supply of grains have both inter-temporal and inter-sectoral functions. When the variation is reduced, inter-temporally diversifiable risks are diversified to the time dimension and washed away, while intra-period remained risks are re-allocated between rural producers and urban consumers. With this re-allocation, rural producers may probably become more in need of insurance coverage and domestic crop disaster insurance becomes viable.

4) Individuals are not able to make full use of "buffer-stock" strategy for diversification because of their limited credit and lifetime. The national or central government may be the best to operate disaster reserves. In perfect conditions, the reserve can enact a risk neutral pool and absorbs all inter-temporally diversifiable risks. The disaster reserve, however, cannot be a perfect substitution for private insurance because of market imperfection and credit limit in accessing international loans. Disaster risks can be maximally diversified if government-operated disaster reserve and private insurance market can work together. Disaster reserve can be used either to provide low-coverage-fair-rate public insurance, or to provide primary insurers with high-layer reinsurance coverage.

According to the model findings, it is believed that mutual insurance among rural producers will be of more practical significance than the insurance contract offered by urban workers to rural producers. Direct subsidy to crop insurance premium charged to rural producers is not recommended, at least from the perspective of economic efficiency. Disaster reserves operated by the state (central) government are powerful diversification instruments, especially when the commercial disaster insurance is expensive. When the buffer-stock strategy is used to manage the risk in grain market supply, its redistribution effect must be carefully examined. According to the result of the model, its effect is in favor of urban consumers rather than rural producers.

Keywords: Inter-sectoral/ inter-temporal disaster risk diversification; dual-economy; crop disaster insurance; buffer-stock strategy; government intervention

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 BACKGROUND

It has been a long discussion on why disaster risks cannot be efficiently diversified with traditional insurance instruments. The experience of major natural catastrophes in 1990s triggered wide-spread concerns that insurance companies may not have allocated enough liquid capital for their underwritten liability (Mürmann, 2000; Froot, 1999a). Meanwhile, statically data reveals that the share of global insured losses of the total losses claimed by natural disasters shows no significant change since 1980s. According to Munich Re (2009), the insurance industry covered only US$ 17bn out of US$ 148bn (11.5%) economics losses claimed by natural disasters around the world in 2008, which is slightly below the average ratio between the insured and total loss claimed. During the period of 1985-1999, the ratio between the insured and total losses are averagely 30% for the group of the most developed countries which is the best, in contrast to less than one-tenth in emerging economy countries (Linnerooth-Bayer et al., 2007).

This question is then called by us as “risk sharing puzzle”: why disaster insurance industry still plays limited role in sharing risks although insurance technology has been progressing rapidly. Generally, it has been as attributed to the insurability of disaster risks. Briefly, a risk is believed to be insurable “if it can be transferred from the initial risk-bearer to another economic agent at a price that makes the exchange mutually advantageous” (Gollier, 2003a). According to the popular viewpoints of the economics of risk and uncertainty, disaster risks are of little insurability because of the direct and indirect transaction costs which deprive the room of mutual advantage. Direct transaction costs refer to the administrative costs for company operation, underwriting contracts, collecting premiums, ceding, and so on. Indirect transaction costs refer to the loading factors attached to pure premium rates induced by information (imperfect and asymmetric), mutual dependence, and imperfect competition in the market, etc.

This thesis is to provide a perspective on the puzzle beyond the insurability hypothesis. From the viewpoint of development economics, insurance is an instrument used not only for transferring risk but also allocating resources. If we put insurance into the context of an economy and in the process of allocating resources for production and redistributing wealth for consumption, following points will be different from what people have learned from existing studies:

1) The efficiency of insurance system is measured by its efficiency in allocating resources and risk-bearing but not how much a risk can be insured. Full-cover insurance against catastrophic risk is not necessarily the first-best choice (Yokomatsu and Kobayashi, 2000).

2) Insurers may not be risk neutral any longer as popularly assumed in economic models. On the one hand, shareholders of local insurance companies may come from the same or nearby regions, and disaster risk among them could be highly correlated. Inter-regional diversification of disaster risk may fail. On the other hand, disaster risks that destroy production are not only borne by producers of the product but also consumers as long as the aggregate output is correlated with the price of the product. Inter-sectoral structure of risk diversification could be different from the general perspective that only the producers are in urgent need of insurance coverage. It could be the case that consumers rather than producers are more in need of insurance against such sort of risks.

3) Inter-regional or inter-sectoral flow of labor, capital and other factors for production could partially substitute for the insurance market to play the role of washing risk. The flow can also induce externality and decrease the efficiency of insurance market in transferring risks. Before an individual chooses whether to insure his future labor income, he can sometimes choose to switch to a sector or region with lower risk. Similarly, capital investment to the risky area can be an alternative choice to offering disaster insurance for investors.

Apparently, points mentioned above cannot be easily covered by popular models assuming that there are a group of individuals facing uncertain endowment and many risk neutral insurers offering insurance coverage to them. Model structures taking both production and consumption processes of an economy into account will be appreciated and new perspectives are likely to appear.

1.2 OBJECTIVE AND MOTIVATION

The objective of this thesis is to discuss the risk sharing puzzle when disaster risk is expected to be diversified across sectors and time periods. It is to reveal the potential factors that undermine the efficiency of natural disaster insurance market in allocating resources and risk-bearing. Accordingly, it is expected to derive policy implications on how such inefficiency can be improved through government intervention.

Why inter-sectoral?

The concept of “inter-sectoral” is of even importance in economics as the concept of “inter-regional”, since sectors rather than regions are the places where production activity is generally assumed to take place. If the discussion is to put in the context of economic processes of production and consumption, it is natural to consider inter-sectoral issues. Disaster risks can be diversified across sectors because economic sectors are asymmetric in terms of exposure and vulnerability to risks. It is also because products of sectors play different roles in maintaining welfare states for individuals. The necessity of products determines the relative degree of risk-bearing between producers and consumers.

The inter-sectoral aspect of disaster risk diversification has not been attached much concern. Researchers interested in risk and insurance work with highly abstracted models without the context of production and consumption process. Researchers in the field of public economics are more concerned about the inter-regional issues. In their models, there are several asymmetric regions while there is only one sector or several homogeneous sectors. Macro-economic models with multi-sectors do emphasize the asymmetry among sectors but they focus more on the unique role of sectors in long-run economic development. Risk diversification is only put into the context of cross-period saving and consumption.

Disaster risk financing for the agriculture sector is a typical inter-sectoral issue that a number of problems have not received convincing explanations. For instance, why don't governments just let rural producers switch to the manufactory sector so that less people are borne to the risk in agriculture production? Why has multi-peril crop insurance failed in many countries? Is it appropriate to give crop insurance heavy subsidy with tax-payers' money? Note here that questions raised above are indeed inter-sectoral issues rather than the problem regarding only agriculture sector. Sectors are not independent but linked by flow of labor, capital, other factors for production, and goods. Risk management for agriculture sector is not only the matter of rural producers, but it determines all other aspects of an economy, e.g. the resource allocation between sectors, availability of agriculture products, and well-being of consumers. Risk in the agriculture sector takes a substantial partition of the risk taken by the entire economy.

Why inter-temporal?

Inter-temporal disaster risk diversification is not new to us. It is becoming more and more important as the effectiveness of inter-regional risk diversification is getting weak for the geographically up-scaling impact of natural disasters. Meanwhile, it is a powerful diversification strategy that has not been well implemented by primary insurers. This is one of the root causes that primary insurers are so vulnerable in front of "big" ones. It is of great meaning to re-visit those drawbacks of individuals and primary insurers in managing the risk by using "buffer-stock" strategy, and suggest the indispensible role of governments in such systems.

Why the government?

The relationship between decentralized and centralized approaches, or market mechanism and government planning, is one of the most long-lasting topics in economics. The necessity of involving governments in financial management of disaster risk has been realized since the mid of 1990s (Kleindorfer and Kunreuther, 1999; Kunreuther, 2000; Kunreuther, 2001; Scawthorn, 2006). As for inter-sectoral issues, the structure of the problem itself requires that the government has to be taken into account, because inter-sectoral monetary transfers are used as a redistribution policy widely carried out by governments in many countries. As for the inter-temporal aspect, state governments have such a special role in running disaster reserve that cannot be replaced by any other economic agents.

1.3 CONTEXT AND FOCUS

Discussion on inter-sectoral disaster risk diversification in this thesis takes a focus on risk diversification between agriculture sector and manufactory sectors. Models are put in the following context. Given the role of agriculture sector in an economy and its vulnerability in terms of disasters, direct monetary transfers are paid from tax-payers to agriculture producers in many countries. Government policies are expected not only to provide higher and more stable income to producers but also to create incentives to attract rural households to continue farming. Nevertheless, these policies have been doubted for inducing economic inefficiency as the later piece of effect masks the market signal for resources and risk allocation. The problem is a trade-off among economic efficiency, equality, and risk-bearing. On the one hand, if the government frees the migration and allows factor markets to work with less institutional friction, there may not be enough factors allocated to agriculture production and the self-sufficiency of foodstuffs is at stake. On the other hand, if the government attracts or even forces a part of population to stay in the agriculture sector, it is equivalent to force them to bear the risk during the process of producing agriculture products. In order to provide some rationale for governments to make decision on this trade-off, the following issues are focused in this thesis:

1) Should the migration behavior of rural labors be controlled, provided a first-best disaster insurance market in place?

This question exactly addresses the key issue mentioned in the previous texts that whether a first-best insurance market (insurance market without any institutional constraints or transaction costs) can efficiently allocate resources (number of labors allocated to each sector) and risk-bearing. If the insurance market is efficient, then it can be claimed that government policy is unnecessary to change the migration behavior of potentially mobile labors.

2) Is the direct subsidy to crop insurance premium charged to rural producers justifiable with the criteria of economic efficiency?

Direct subsidy is a popular intervention policy regarding risk management for the agriculture sector, although the rationale of the policy is still controversial. This thesis will excursively discuss the purpose of government intervention, putting in the context above, in establishing a viable crop insurance market and help it play the role of allocating resources and risk-bearing in an economy.

3) What is the relationship between government grain reserve policy and crop disaster insurance programs?

In many countries there are state-owned grain barns used for store grains with large quantity. With the barns, stock-buffer strategy can be applied to diminish inter-temporal variation of grain output so that the risk in grain production and supply can be diversified in the time dimension. Provided the fact that both of grain reserve policy and crop disaster insurance program in place, what is the relationship between them in risk diversification in an economy, substitutable, complementary, or something else?

4) Why is it necessary to involve governments in inter-temporal diversification of risks?

This question addresses the generalized form of inter-temporal risk diversification. Grain reserve policy is a special application of the buffer-stock strategy in managing the variation of substantial goods. The question is equivalent to ask why the capacity of insurance market in diversifying disaster risk inter-temporally is so limited and how can a government use fiscal as well as policy instruments to enhance the capacity of disaster risk diversification across time periods?

Each of the questions corresponds to one out of four models in this thesis. The manner of description and analysis follows the style of public economics and welfare economics. Discussion is mainly put in analytical and qualitative manner. Arrow-Debreu Economy with dual-sectors or dual regions is the basic framework for discussion. Disaster risk is the key element throughout the entire thesis, which is modeled with the collective risk theorem (Malinvaud, 1972; Malinvaud, 1973).

1.4 STRUCTURE OF THE THESIS

This thesis consists of 7 chapters, covering two major aspects with 4 economic models. The structure is depicted in Fig. 1-1.

This Chapter mainly describes the background, motivation, and focus of the study. It also provides the readers with an overview on the structure of the entire work.

Chapter 2 gives a systemic review on the state-of-the-art of economic literature discussing the efficiency of disaster risk diversification through decentralized approaches. It summarizes factors that hamper disaster insurance market from efficiently or fully diversifying disaster risk. Accordingly, policy implications against each type of causes are also summarized. The China Agriculture Policy Insurance Pilot Program and the Japan Earthquake Reinsurance system are introduced in the second half of Chapter 2 as examples of government initiatives in diversifying disaster risk across sectors and time periods.

Chapters 3, 4, and 5 mainly contribute to the inter-sectoral aspect of risk diversification of agricultural disaster.

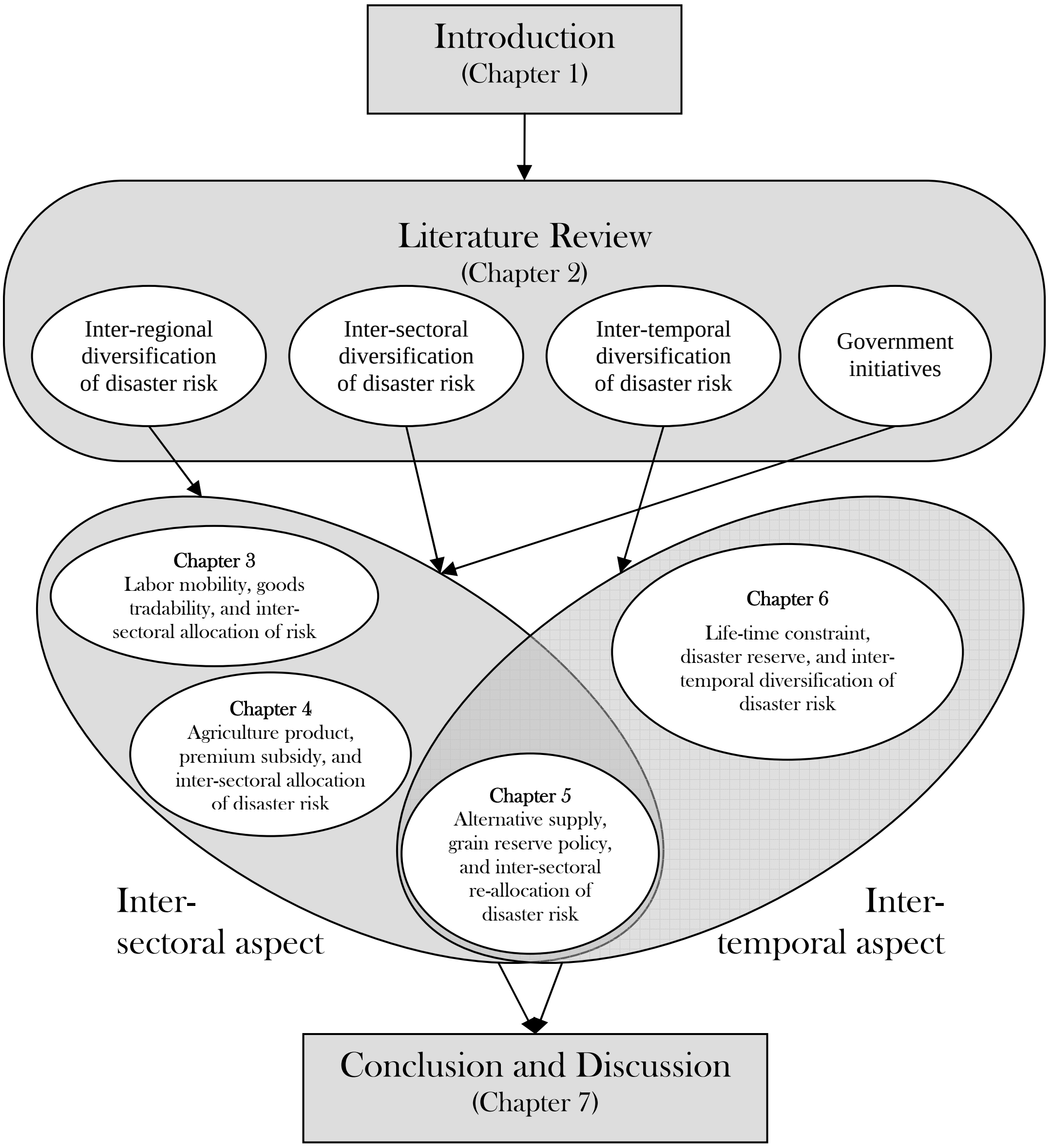


Fig. 1-1 Framework of the thesis

Chapter 3 presents a simple dual-economy model incorporating migration and collective risk. It mainly addresses that whether the migration behavior of rural households should be controlled by the government. In this model, labor allocation is used to represent the allocation of both resources and risk-bearing. Labor mobility and goods tradability are assumed to be susceptible factors that may cause negative externality in the allocation with decentralized approaches. Government intervention, either in the form of lump-sum transfer or direct subsidy to insurance premium, is designed to improve efficiency performance. In this chapter, sector-specific features are framed with the *ex ante* and circular migration structure while goods-specific features are not really touched upon.

Chapter 4 exclusively aims at evaluating the hypothesis advocating direct premium subsidy to crop disaster insurance. The model has succeeded to the major assumptions on sector-specific features and migration structure in Chapter 3. It gives clearer description on goods-specific features so that the rural goods in the model truly refer to agriculture product. The model assumes a static and closed dual-economy where the prices of goods are endogenously determined. In this sense, uncertainty in the yield and uncertainty in the price of agriculture product are inter-linked. By using equilibrium analysis, producer’s behavior under a generalized form of insurance is analyzed. Comparative statics are carried out to revel how output decision is affected by premium subsidy. We further discuss labors’ migration behavior under perfect mobility assumption when premium subsidy is paid to producers. Finally the welfare state of the economy is investigated to check whether the premium subsidy brings efficiency loss or gain.

Chapter 5 tries to explain the gap between the findings of the model in Chapter 4 and the reality. It claims that the period-by-period market clearing structure is one of the essential reasons that all disaster risks are borne by urban workers (mere consumers of the agriculture product). In this sense, an extension of the basic model is provided in this Chapter to discuss the impact of grain reserve policy on the allocation of risk-bearing between sectors. Firstly we derive the social optimal diversification strategy if the technology allows perfect inter-period storage of grains. The risk-bearing pattern under various government intervention strategies, including social insurance system in the substantial form, social insurance system in the monetary form, and intervention strategy following non-arbitrage principle, are examined. Further more, the viability of domestic first-best disaster insurance market is checked under each intervention strategy to reveal the relationship between grain reserve policy and domestic crop disaster insurance.

The model in Chapter 6 enriches the discussion with respect to inter-temporal issues of disaster risk diversification. The model shows the limitation of insurance market in diversifying disaster risk inter-temporally. It employs the classical two-period-overlapping-generation structure to represent the constraint of limited lifetime of individuals which simultaneously limits the lifetime of insurance contract. It essentially models the dynamic funding process of the disaster reserve which is the kernel instrument for diversifying disaster risk inter-temporally. With the inter-temporal approach, the model provides an alternative to enhancing the capacity of insurance market by constructing disaster reserve operated by the government.

Chapter 7 concludes the entire thesis. Policy implications are put forward according to the explicit findings of models.

Chapter 2

The state-of-the-art of disaster risk diversification

This chapter gives the readers a brief review of the state-of-the-art of disaster risk diversification. It consists of two parts. In the first part, up-to-date literatures are reviewed. Firstly, it introduces the traditional perspective on the insurability limit of disaster risk. Then, literatures on risk financing and resources allocation are classified into three major sub-topics, the inter-regional, inter-sectoral, and inter-temporal aspects of disaster risk diversification. The second part of this chapter brings two practical cases in reality to demonstrate how governments are diversifying disaster risk across sectors and time periods with policy as well as fiscal instruments.

2.1 LITERATURE REVIEW

2.1.1 Traditional viewpoints on insurability puzzle of natural disaster risks

Insurability is a more practical version of the discussion on insurance market efficiency issues. Meanwhile, the concept of insurability is narrower than the general concept of insurance market efficiency. The actuarial view of insurability is whether the Law of Large Numbers can be applied. In other words, a risk is insurable if the maximal potential loss is finite and risk units are not mutually correlated. Given this narrow definition, disaster risks can never be insurable since disaster damage is of low frequency but bulky arrivals.

Gollier (2003b) has given a more general definition on insurability that “a risk is uninsurable if given the economic environment no mutually advantageous risk transfer can be exploited by the consumer and the suppliers of insurance”. Following this definition, he has listed several factors which are believed to have squeezed the mutual advantages through exchange of insurance contract. These factors evolve to various kinds of “loading factors” reflecting the necessary fund to cover various kinds of transaction costs to keep insurers solvent. They are exactly the elements that significantly increase the cost for a risk-bearer to transfer its risk and diminish the potential mutual advantages. Transaction costs here are induced by a number of factors, including administrative costs and other indirect transaction costs induced by information (imperfect and asymmetric), mutual dependence, heterogeneity, and imperfect competition in the market, etc.

Administrative costs

Administrative costs are a major item in all insurances. They are the least in life insurance but account for 30-40% of the premium rates when it comes to property and casualty insurance (Arrow, 1996). These costs are generated in the process of operating business of insurance companies, e.g. costs for daily operation of business, advertising, underwriting, collecting premium, loss inspection, etc. Administrative costs for crop insurance in developing countries are significantly high, particularly. Insurance companies have to spend a lot of fund to persuade rural farming households to participate in crop insurance system. The farming population is generally huge and the spatial pattern of settlements is so scattered. The costs for transportation and salary per policyholder in the process of collective premium could even be higher than the premium itself.

Imperfect information

Imperfect information refers to the fact that our knowledge on natural disaster risks is so limited, although our disaster insurance system has been running for several decades and we may have historical data records of hundreds of years for certain hazards. Catastrophic risk is known for its low frequency and bulky arrivals and our historical data is not enough to diminish the uncertainty attached to the risks. It is very difficult to make unbiased estimation from insufficient data records with statistical approaches (generally Bayesian). Catastrophe modeling is another way to expand our knowledge but models are not ready yet to solve the problem because of considerable variation in quality and sophistication (Jones, 2007). As a result, insurers have to add high loading factors on the actuarial premium rate to reflect the cost of ambiguity (Kunreuther et al., 1995; Schade et al., 2002), which could be 1.8 times higher than when insuring events with well specified probability and loss estimation (Kunreuther et al., 1993).

Mutual dependence

Mutual dependence across risk units is the most significant difference between disaster risk and other property and casualty risks. Disaster risk is known as a kind of collective and idiosyncratic risk. The Law of Large Numbers cannot apply. In theoretical discussions, mutual dependence has already undermined the insurability (Yokomatsu and Kobayashi, 2000). In a more practical manner, cumulative density functions (*c.d.f.*) and Exceedance-Probability (*EP*) curves meeting actuarial accuracy can hardly be derived for mutually dependent risks. Again, insurance companies will choose the similar method as against imperfect information – let policyholders pay for the ambiguity of the risk. Here the ambiguity is not induced by imperfection information but by our limited techniques to model and price the risk.

Adverse selection

Asymmetric information and heterogeneity among policyholders have resulted in the so-called "adverse selection" problem revealed by the seminal work of Rothchild and Stiglitz (1986). In their model, an insurance market cannot reach equilibrium if there are two groups of potential policyholders who are asymmetric in terms of disaster. If the insurance company prices the premium rate on the basis of average probability distribution in the risky population, less risky individuals will always find the premium rate too expensive. They will choose partial coverage or even zero coverage. In contrary, more risky individuals will exactly find the premium rate cheap and get themselves over-insured. The insurance company, however, can only distinguish between potential policyholders of low risk and high risk at substantial transaction costs. To keep the insurance pool actuarially solvent, insurance companies may choose the higher premium rate and consequently the majority of policyholders are under-covered.

Asymmetric information

Asymmetric information is the root cause of moral hazards. Policyholders always hold more information with higher level of details about the insureds. The information could be the healthy condition of the insured, the construction quality of a building, or the productivity of a piece of land. Meanwhile, policyholders' behavior in risk prevention is not observable or observable only with high transaction costs. For instance, farming households may intentionally simplify the necessary procedure in production and the supposed output is reduced so that indemnity is more likely to occur. These situations are the so-called *ex ante* moral hazards. On the other hand, insurance fraud could happen since the inspecting and auditing of actual loss claimed by risks are costly. Such a situation is named *ex post* moral hazards (e.g. Townsend, 1979; Mookherjee and Png, 1989). In order to prevent moral hazards from happening, insurance companies generally have to afford an amount of costs for evaluation of insureds, inspection of risk-taking behaviors and auditing losses. Those costs are the indirect transaction costs induced by asymmetric information.

Imperfect market competition

It is hard to say that disaster insurance market is purely competitive as assumed in economic models. The nature of disaster risk determines that the market cannot be perfectly competitive, as only large companies who are able to set up large and well diversified portfolios can survive in the battle against catastrophe as well as their competitors. Besides, large companies have comparative advantages in their business, e.g. catastrophe modeling, pricing, and rating. International reinsures show even larger market power than primary insurers. It can be detected from the underwriting cycles and alternating phases of "hard" and "soft" markets with the arrival of mega-catastrophes (Guy Carpenter & Company, 2007). The existence of cycles implies that the response of insurance markets to large events losses is not necessarily fully efficient in the sense that prices are not predictable and supply shortages may develop periodically (Cummins, 2007). It is believed that the cycles are driven by capital market and insurance market imperfections with high friction preventing the free flow of capital (Cummins and Danzon, 1997; Cummins and Doherty, 2002). Fortunately, the situation is going to change that CAT bonds are believed to be attracting much more interest from institutional investors with a booming market since 2005 and they are more competitive with conventional reinsurance than earlier analyses may have suggested (Cummins, 2008). Coupled with the new funding approaches for reinsurance such as sidecar, a more competitive disaster risk financing system is likely to emerge in the coming years and the efficiency of the market for financing the high-layer losses is expected to improve.

Discussion above includes the deep insights provided by popular wisdom about the insurability of disaster risks. It has covered economic models considering the ideal condition and observations to the issues in reality. Those economic models have mainly assumed that a population of individuals faces some risk that makes the welfare states of individuals uncertain. A group of insurance companies come to offer insurance coverage and then with various kinds of scenarios insurance behavior of individuals and the efficiency of insurance market are discussed. The theoretical discussion with ideal worlds is not exhaustive, however.

2.1.2 Inter-regional disaster risk diversification

Classic economic models on resources allocation among multi-jurisdictions

As stated in the introduction, disaster risk diversification has to be taken into the context of resource allocation and wealth redistribution. Therefore, the fundamental issue of inter-regional disaster risk diversification is the inter-regional resources allocation. It has been a classical topic with a long history in the field of public economics that how resources can be efficiently allocated among multiple jurisdictions. The topic is framed in the following way:

In a small world where there are local jurisdictions, 1) what is the optimal distribution pattern of resources among those local jurisdictions when local conditions, either symmetric or asymmetric, and openness of local jurisdictions are taken into account; 2) can such optima be achieved through decentralized way; and 3) if not, what kind of centralized intervention approaches can be helpful to achieve higher efficiency? Local conditions here may include natural resources endowment, human capital endowment, technology, people’s preference, and risk and uncertainty, etc. The openness refers to the facts that labors as well as commodities (including goods and non-labor factors) are allowed to move among regions at some costs. Factors that can potentially affect the efficiency of risk-sharing across jurisdictions include imperfect labor mobility (costly migration of labor among jurisdictions), tradability of commodities, provision of pure or non-pure public goods, etc.

Flatters et al. (1974) develops a simple but representative model of this type. The model mainly addresses the efficient resources (labor) allocation problem in a multi-region economy. In a small world of two regions, there are a fixed population of workers who are perfectly mobile between regions and a class of landlords who own all the land in both regions and collect all land rents. It is known that both regions produce a single homogeneous commodity which is partly used as a private good and partly as a pure public good. The expenditure of the public good is financed by levying tax from local residents.

The discussion in this model is quite a good template for studies in this field. It firstly discusses the optimization problem for single regions which is to maximize per capita utility of individuals. 2) The second step is to discuss the social optimum, the efficient allocation of labors between two regions, assuming there is a wise central planner governing both regions. 3) The third step is to check whether this social optimal allocation can be attained through market approach. The analysis implies that 1) the marginal product of labor should be equal to per-worker consumption of the private good; 2) centralized allocation must equalize per-worker utility levels between regions; the necessary condition for social optimum requires that the sum of the marginal rate of substitution of both the private and public good should equal the marginal rate of transformation, and the workers should be allocated between regions to equate the net social marginal product of labor; 3) workers will allocate them optimally only if taxes paid per worker are identical between the two regions; in this model if the compensated price elasticity of demand for the public good is minus one, free migration of labor will produce a Pareto-optimal. Otherwise a federation should be set up to conduct intervention.

This paper provides several extensions which illuminate major subjects for further discussion. Market equilibrium with free migration is likely not to be efficient if 1) there is congestion in public goods usage; 2) the technology of production is non-constant-return-to-scale; or 3) there is differential locational preferences that some workers derive additional utility simply from being located in some region rather than others.

For more details and systematic literature review in this field, readers can refer to two famous books (Oates, 1972; Wildasin, 1986), which are excellent summary of the state-of-art of this field.

Inter-regional disaster risk diversification

Basically, models discussing inter-regional disaster risk diversification can be regarded as a branch of the overall structure mentioned above with a special concern attached to risk and uncertainty. Several problems are extensively examined, when it comes to disaster risk diversification rather than purely resources allocation:

1) In which way collective risk (risk units are not necessarily independent of each other) can be optimally financed?

2) In the basic framework of resources allocation among multi-jurisdictions with uncertainty and risk, what is the modified Samuelson Rule for the investment on public goods such as disaster prevention/ mitigation infrastructures?

3) Given the openness of jurisdictions, what is the social optimal allocation of resources and can market approach achieve such kind of efficient allocation?

In the preceding part of this section, we are going to review several representative models that have touched upon the three problems listed above.

1) Idiosyncratic/ catastrophic/ collective risk and the Malinvaud-Arrow Insurance

When it comes to disaster risk diversification across different regions, the largest difference from the classical or traditional models of resources allocation with uncertainty is the definition on the risk. Disaster risk is a kind of idiosyncratic, catastrophic, or collective risk which is not necessarily independent across risk units. Accordingly, the Law of Large Numbers cannot apply in most cases and disaster insurance should not be "fair" then.

Malinvaud (1972; 1973) has firstly put forward the sound definition of "collective risk". He interpreted "collective risk" as a two-stage compound lottery. Imagine that there is a box of balls. First, the nature decides how many balls to pick out from the box, which is called the "collective state" of the lottery game. Then it decides which specific balls are picked out. Collective states are labeled by $t = \{0, 1, \ldots, T-1\}$ which are independent and exhaustive divide of the possible events. For each collective state, there is probability $\pi(t)$ with $\sum_t \pi(t) = 1$. For each ball it has a state of "in/out", which is called "individual state". Individual states are labeled by $s = \{0, 1, \ldots, S-1\}$ which are also independent and exhaustive divide of the event space. When the two-stage lottery game is finished, each ball must be in a certain joint state (s, t). For a ball of certain type *i*, there is a probability vector of falling in individual state *s*, $\pi_i(s)$ with $\sum_s \pi_i(s) = 1$ and a conditional probability vector $\pi_i(s \mid t)$ which describes the probability of this ball falling in an individual state *s* when a certain collective state *t* happens. According to the definition of conditional probability, it holds that $\sum_s \pi_i(s \mid t) = \pi(t)$ and $\pi_i(s,t) = \pi_i(s \mid t) \cdot \pi(t)$. For each ball, joint states are independent and exhaustive divide of the event space and therefore $\sum_{s,t} \pi_i(s,t) = 1$. One more interesting feature of the collective risk concept is that when a certain collective state *t* is chosen, there are exactly a proportion of $\pi_i(s \mid t)$ balls falling in individual state *s*.

The "collective risk" theorem has not made any explicit definition of the mutual dependency among risk units. The relationship between the occurrence of a certain individual state and a certain collective risk is clearly bridged via the conditional probability but the relationship is not known between the occurrences of individual states of two risk units. In this sense, it is a very nice tool to formulate disaster risk analytically. Disaster risk can then be interpreted in a similar way: firstly, the nature determines a collective state, which can be the geographical location, severity (intensity), area affected, duration, number of victims and economic loss. Secondly, individual states correspond to the status of each household in the disaster, e.g. its loss in human capital (injury or death), fixed assets and capital. As long as the probability vectors are known, it is quite straightforward to discuss diversification and transfer of disaster risk.

Based on this theorem, Cass et al. (1996) and Yokomatsu and Kobayashi (2000) have constructed a kind of "perfect insurance" which can most efficiently finance collective risk. It is then named "Malinvaud-Arrow Insurance" (M.A. insurance) because of the contribution of

Malinvaud in collective risk theorem and the use of Arrow security in this insurance system. A M.A. insurance system consists of two sub-systems. The one is a mutual insurance system which transfers the individual risk among individuals of the same type. Here “same type” means they have same probability vector of individual states and conditional probability vector. The other is an Arrow security market which allows individuals of different types to transfer the collective part of the risk.

The two models mentioned above are constructed in pure exchange economies. There is a population of individuals in a small economy, locating in different regions and consequently exposed differently to disasters. Individuals are not allowed to move among regions and therefore they eternally belong to predefined groups. At the beginning of each period, the nature determines a collective state and individual states. Each individual is then endowed with a certain amount of goods which depend on his/her individual state. M.A. insurance system is then introduced into the small world to see how efficiently disaster risk can be diversified through the market insurance approach. There are several important findings from the models:

(1) If the risk allocation is to achieve social optimum in terms of maximizing weighted aggregate expected utility, social optimal condition requires that: a) marginal utility should be equalized across all individual states; b) individuals of the same type must be allocated the same amount of goods; and c) weighted marginal utility with respect to state-contingent goods should be equalized across all individual types in all collective states.

(2) When transaction costs is not taken into account, M.A. insurance can efficiently diversify collective risk in this small economy and achieve an equilibrium equivalent to social optimum.

(3) M.A. insurance is not a fair insurance system and therefore full coverage is not efficient. The mutual insurance subsystem is fair and individuals purchase full mutual insurance coverage. Moreover, M.A. insurance will induce “regressive redistribution” effect that the wealthier/ safer absorbs more surplus than the poorer/ more hazardous.

The collective risk theorem and M.A. insurance provides us with the most fundamental but critical model to formulate catastrophic risk in the framework of Arrow-Debreu Economy. Since it is the most efficient insurance system in terms of collective risk, its equilibrium is regarded as the “insurance optimum” and generally derived as the reference to evaluate the efficiency performance of other types of insurance.

2) Inter-regional factor mobility and risk diversification

Inter-regional flow of factors and commodities are always the topic that models in this field have to take into account. The model of M.A. insurance is derived in the framework without such kind of flows. In this section, models with more generally framework considering trading of goods and migration of labors will be introduced.

Wildasin (1995) has formulated a simple model with potential mobile factors and uncertainty, showing that "greater factor mobility enables factor owners to pool industry-specific, region-specific or occupation-specific risks (due to uncertain technology or terms of trade)". It describes an economy with a single homogeneous output using one potential variable factor of production and one or more fixed factors. For instance, the potential variable factor can be labor while the fixed one can be land and then it refers to agriculture production. The production is then determined by the level of variable factor input and uncertain technology. The variable factor is assumed to be mobile. When it is regarded as inter-jurisdiction matters, it refers to the migration of labors in/out of domestic region, which is costly. Meanwhile, local governments are conducting redistribution of return to factors with a lump-sum tax after the state of nature is known, from one factor to the other one. Then migration equilibrium requires that the net return to the variable factor be equalized across locations.

Then the model excursively discusses the allocation of risk between variable and invariable factors. For the ease of tractability, it employs quadratic production function with respect to the variable factor, showing linear marginal productivity. In this case, when factors are less mobile (with sufficiently high migration costs), domestic factor prices will not be affected by external factor prices. When factors are sufficiently mobile, domestic factor prices are linked by "spatial arbitrage" through factor mobility to external prices.

Three cases are discussed and compared in the model. (1) With the absence of government income redistributive policy, factor mobility and risk-bearing of the fixed factor is negatively correlated, partially because of the special form of production technology. When variable factors are immobile, owners of fixed factors face no income risk but when variable factors are perfectly mobile, all risk is shifted to the owners of the fixed factor but the average income of the owner of the fixed factor increase. Therefore there is an "efficiency gain" by increasing the mobility of the variable input, in the form of an increase in the mean income of domestic factor owners. (2) The second case is that local governments provide "full cover" insurance to the owners of the variable factor. When factors are immobile, full cover insurance will shift all income risk from the owners of the variable factor to the fixed factor. When factors are potentially mobile, this policy still forestalls any factor mobility for any positive value of migration costs as there is no incentive for owners of the variable input to incur the cost of moving. Still owners of the fixed factor absorb all income risk independent of the level of migration costs. The government policy, however, induces an "efficiency loss" because the mean return to the fixed factor gets lower. (3) In the last case, local governments are assumed to provide partial coverage insurance to the variable input. For any given value of migration costs, net return to the variable input is equal to the return on the external market as fixed but its variance reduces with an increase in factor mobility. On the other hand, the expected return to the fixed input reduces and its variance increases. It is still believed that government policy induces "efficiency loss" in this sense.

Wildasin's model has provided a generalized perspective on the relationship between economy integration and welfare state in terms of economic efficiency. He believes that economy integration

(integration means factors are more mobile) improves the welfare state of the small multi-jurisdiction economy by increasing expected income. In the specific model, the increase of efficiency in resources allocation accrues only to the fixed factor with the expected income of the variable factor unchanged. It is also interesting to see that government redistribution policy, either partial-cover social insurance or full-cover social insurance, dull the incentives for state-contingent reallocation of the variable input and ruins the gain in efficiency generated from economy integration.

3) Risk sharing and efficient provision of public goods

One representative model on this topic is from Persson and Tabellini (1996) which discusses the tradeoff between risk-sharing and moral hazard in two different fiscal constitutions, the "US system" which redistributes directly between individuals and the "EU system" which mainly conducts inter-government transfers. The trade-off is described as: "federal risk-sharing may induce local governments to enact policies that increase local risk".

In the model, individuals' welfare is measured by a one-good utility function with strictly concave preference. Individuals' wealth is exposed to uncertainty, however. The authors defined the risk in a way quite similar to Malinvaud's collective risk. Firstly it is determined that how many percentage of the population will be in the good state, getting an income of 1 and how many in the bad state, getting an income of 0. This corresponds to the collective state in Malinvaud's definition. Then for each individual, there will be a conditional probability telling about the chance of being in the good state or the bad state, given the collective state as known parameter. The conditional probability, however, is private and not directly observable. The major policy of a local government is to provide "social insurance" that allocates consumption between lucky and unlucky individuals, and to determine the optimal "public investment" in disaster mitigation.

An important assumption is that the policy is determined *ex ante* by majority rule. When only a single local government is considered, "the equilibrium policy maximizes the expected utility of the voter with the median idiosyncratic risk component". In this single government optimization problem, the median voter's idiosyncratic risk is equal to average risk and the majority finds it optimal to support full social insurance in both states of nature. Meanwhile, the median voter equates the expected marginal benefit of investment to its expected resources cost.

When there are two local governments, the discussion extended according to the "EU system" and "US system". When the "EU system" is adopted, the first-best equilibrium is a cooperative game: (1) each local government carries out full social insurance; (2) inter-government transfer of wealth equalize average outputs in both jurisdictions which is called full-inter-government risk sharing; and (3) the first-order condition for public investment is the same as in the basic model except that the benefits of being in good domestic state spill over abroad through inter-government risk sharing. The second best equilibrium corresponds to Stackelberg Equilibrium when there is a confederation and confederation poll is carried out in advance of local pools. In this equilibrium, inter-government risk sharing is partial while public investment is under-provided. Nash equilibrium is the third-best one which entails full inter-government risk sharing but under-provision of public investment which is even less than the second-best equilibrium. “Moral hazard” problem occurs. If there is a “US-like” federal government in this small world and a centralized social insurance system is provided, it provides more commitment capacity. Direct democracy with simultaneous voting on the federal and local policy instruments replicates the third-best equilibrium, while representative democracy yields the second-best equilibrium. As for the public investment, there are two threshold values that make the majority better off than the third-best equilibrium and the second-best one, respectively.

The model of Persson and Tabellini (1996) has been successful in the way that it touches upon the effect of political constitutions on inter-government (inter-regional) risk sharing. Moreover, its definition on the idiosyncratic risk provides an alternative way of modeling disaster risk. If there is any weakness of the model to be mentioned, then it must be the point that inter-jurisdictional migration of population is not taken into account.

The model from Yokomatsu et al. (2001) has extended the framework to asymmetric regions with household migration. The model describes a small closed economy with two regions, the safe and the dangerous. There is only one commodity produced, which is used for private consumption, public investment on infrastructure and recovery of damaged infrastructure by disasters. It is assumed that only the dangerous region is affected by disasters. Disaster risk is defined as Malinvaud’s collective risk. Household migration reaches to equilibrium when expected utility of households in both regions are equalized. Two local governments are providing policy instruments which maximize per capita expected utility of its citizens.

The first-best or social optimal equilibrium of this model is to (1) equalize the marginal benefit and marginal cost of moving one more household to the other region; and (2) optimal disaster prevention investment is to equalize social aggregate willingness to pay and the marginal individual cost for the public investment. The authors then use the social optimal condition to test two policy instruments: a) the central government provides full-cover social insurance to the households living in the dangerous region; and b) the local government of the dangerous region purchase M.A. insurance in the market from the other local government. Compared to Persson’s model, full-cover insurance in this model cannot lead to social optimum because of the openness between regions: the dangerous region will be over-populated. Policy instrument B can lead to social optimal allocation of households as well as risk, but it cannot guarantee the Samuelson rule for optimal disaster prevention investment of the social optimum. It is because the decision is made by the local government of the dangerous region who does not take all households into account. The model suggests that the private insurance market approach be more favorable but intervention from the central government is necessary to guarantee social optimal disaster prevention investment.

Similar to the two models mentioned above, the model from Hercowitz and Pines (1991) has addressed the problem of “risk-sharing” through inter-government donation in a multi-locality framework. The authors categorize the study as a sort of “fiscal externality” problem in an uncertain world. The difference is that traditional “fiscal externality” problem concerns positive externality induced by immigration which lowers per capita tax of providing public goods while this model focuses on negative externality of immigration which lowers subsidy each local resident can obtain. The uniqueness of this model, compared to another two, is that it takes migration into account and is framed in a dynamic manner with infinite time horizon.

It is necessary to observe the dynamic structure of the model. It describes a small economy with two regions, unlucky (U) and lucky (L), with a fixed population able to migrate in between at a certain transaction costs. Income of an individual consists of two parts, labor productivity and a non-labor income. The non-labor income represents the uncertain nature of an individual’s income, described as a kind of “manna” falling from heaven in region L only. Therefore, individuals in the unlucky region can get such kind of “manna” only when there is an inter-government transfer or donation of wealth. Each individual lives forever and decides whether to stay in his current region for one more period of move to the other region. Then the decision-making on migration is put into the same structure of sequential decision-making over two alternatives as in job-search models.

The model then discusses the social optimum, stationary population distribution, and the possibility of achieving social optimum via decentralized approaches. The social optimum simply requires that manna income should be differential to zero. In other words, individuals should enjoy the same amount of manna irrespective of his/her location. When it comes to decentralized approach, the authors consider Nash equilibrium of benevolent regional governments. If L’s government is myopic regarding the effect of interregional donation, then it never chooses to donate any share of the manna to region U. When governments are assumed to be farsighted while migration is free, the model collapse to a static and period-to-period structure and the decentralized equilibrium guarantees the social optimum. When migration is costly, region L donates partially to region U and there will be a critical value of the total manna beyond which region L starts to donate. These results diverge from those obtained from problems of static framework.

Models mentioned in this section are comprehensive representatives of the studies regarding inter-regional disaster risk diversification. Asymmetric endowment, costly migration, inter-government or inter-regional transfer of resources and risks, and crowed-up problem of population, are common elements of models of this type that have been extensively focused on. It is important to percept that insurance instrument is not only used to transfer risk, but also a powerful tool for resources allocation.

2.1.3 Inter-sectoral disaster risk diversification

The most popular discussion regarding inter-sectoral issues of disaster risk diversification is between the agriculture sector and manufactory sector, both of which exhibit the most significant difference in terms of both economic development and disaster risk. In this sub-section, literatures regarding agriculture sector and disaster risk, the role of agriculture sector in an economy, and the popular issues regarding agriculture insurance are summarized. Again the author wants to emphasize here that disaster risk diversification for agriculture sector is not only the matter of agriculture sector itself. By putting the discussion in the context of an entire economy, insuring agriculture producers implicitly means that a part of the risk is transferred to shareholders from other sectors. It is indeed a cross-sector issue.

Speciality of agriculture sector in terms of disaster risk

"Agriculture is subject to greater risk and uncertainty than most other sectors of the economy and therefore is more in need of government disaster assistance than most other sectors" (Goodwin and Smith, 1995). There are several reasons attributed to this fact:

(1) Vulnerable agriculture production

Agricultural production is highly dependent on natural environment and consequently exposed to variation of those conditions – natural disasters. Agriculture production, particularly crop production, has strict requirement on a bundle of physical geographical conditions, e.g. soil, precipitation, hours of sunshine, wind, temperature, accumulated temperature, etc. Large fluctuation in those critical conditions can destroy a large proportion of crop yield – in that sense, natural disaster strikes agriculture production. Unfortunately, global environmental change is increasing the instability of local weather systems as well as large scale regional climate systems, making extreme events to occur more frequently. Such a change also determines that agriculture disaster are generally of quite large scales and victims of one single event can easily be numbered and geographically concentrated – a sort of typical collective risk that the Law of Large Numbers cannot be applied.

(2) Insufficient provision of infrastructures to mitigate damages

Compared to other sectors, agriculture sector is covered by the least disaster mitigation infrastructures, particularly in less developed countries. As a result, agriculture output can be destroyed by small events with high frequency as they are even not provided with even the most basic level of protection. The first reason for the under-provision is that the product of agriculture sector is generally intermediate goods with low added-value and therefore provision of disaster mitigation infrastructure in rural areas is relatively expensive compared to other sectors. Secondly, population density in rural area is almost surely much less that in cities. It will be difficult to finance the costs of public investment through local tax revenue. Per capita costs for such provision are much higher for agriculture sector than other sectors. Last but not the least reason is that rural communities are generally less powerful in regional or national politics and their need are not easily to meet.

(3) Inelastic demand vs. instable supply

Agriculture producers are not only affected by risks of natural disasters but also risks in the market. The demand of agriculture products, especially necessary products for human beings, is always inelastic. Inelastic demand is a good thing in some sense that the total demand does not change rapidly so that resources allocated to this sector can be stable in the short run. When the randomness of successful cropping goes large, however it turns to a tough trade-off: if rural producers produce a lot but disaster does not come, there will be large amounts of surplus and producers will suffer from low price. If alternatively they produce not much but disaster does come, the aggregate output may not necessarily meet the social aggregate demand. In other words, it is a sort of puzzle of matching inelastic demand with random supply from the producers.

(4) Little access to financial markets

When it comes to income risk, there are quite a number of financial instruments available to hedge the risk, e.g. insurance, further markets, and so on. Agriculture producers in less developed countries, however, generally have little access to financial markets. In those centuries financial sectors are under-developed and there are few securities designed for disaster risk. Meanwhile, the majority of producers is less-educated and does not have enough knowledge on financial instruments. Additionally, the transaction costs for agriculture producers are higher than workers in other sectors – at least they have to afford an extra amount of transportation costs in moving between homes and security exchange board.

5) Less mobile factors: land and labor

Less mobile factors for agriculture production is another aspect that prevents efficient risk sharing between agriculture and nonagricultural sectors. Land for agriculture production is immobile as the geographical location is fixed. In many cases, it is also not possible to switch the type of use since the switch is irreversible and prohibited by land use plan. Labor for agriculture production is less mobile, too. In many countries the outflow of rural labors to the urban sectors are controlled institutionally, e.g. the household registration system in China, partially because of the development stress of large cities.

The role of agriculture in an economy

It is important to know the role of agriculture sector in an economy when it comes to the necessity and approaches of inter-sectoral risk-sharing between agriculture sector and other sectors. Economics has had a long and intensive discussion on this issue with plenty of literatures, either in a descriptive way (e.g., Johnston and Mellor, 1961; Johnson, 1993; Timmer, 1992) or with macroeconomic models (e.g., Steger, 2000; Picard and Zeng, 2005; Bennett and Dixon, 1996; Irz and Roe, 2005; Sah and Stiglitz, 1994). A general but rough review on the works which is essentially related to this thesis has been put in the following texts.

The discussion on the role of agriculture in an economy ascends to the Physiocrats in the mid-eighteenth century and which was central to the early development of analytical economics by Adam Smith, David Ricardo and Thomas Malthus. The most seminal modern work comes from Johnston and Mellor (1961) “The Role of Agriculture in Economic Development”. In this article, the authors have summarized the role of agriculture into five aspects: (1) Agriculture sector provides products to meet the demand which increases substantially with economic development. (2) Exporting agriculture products may be one of the most promising means of increasing income and foreign exchange earnings. (3) Agriculture sector provides other expanding sectors of the economy with almost unlimited supplies of labor forces. (4) Agriculture in less developed countries can make a net contribution to the capital required for overhead investment and expansion of secondary industry; (5) Rising net cash incomes of the agriculture labors may be important as a stimulus to industrial expansion.

In late 1960s, Soviet Economist Preobrazhensky put forward his famous work discussing about economic development and squeezing agriculture sector (Preobrazhensky, 1965). There are two famous propositions in his work: (1) the state can increase accumulation by moving the terms of trade against peasants by increasing the size of scissors (the degree of squeezing agriculture); (2) by turning the terms of trade against peasants, it is possible to accumulate in a manner that the economic position of industrial workers will not deteriorate. His theory has been adopted by socialism countries, such as the Soviet Union and the P. R. China where the accumulation process is finished by squeezing farmers. His theory also genders long-lasting discussion. Sah and Stiglitz (1994) have checked the validity of his propositions and found that his first proposition is correct but the second one does not hold. "… a price squeeze on the peasants leads to a decrease in the welfare of industrial workers, just as it leads to a decrease in the welfare of the peasants", as corresponds to point (5) of Johnston and Mellor.

With the post War revolution in production techniques and improving understanding of the role of markets as well as governments, the power of agriculture in an economy changes substantially. Timmer (1992) has revisited this controversial topic and points out three important issues: (1) agriculture is a declining industry during the process of economic growth; (2) in a market-oriented economy, the way supports in technological innovation and funding of infrastructures can be privatized in an appropriate way; and (3) the value of agriculture sector cannot be evaluated by the market as it is serving non-market contributions to economic growth, which can easily induce market failure: a) impact of food price stability on investment decisions; b) contribution of agriculture growth to growth in total factor productivity; c) alleviating poverty; and d) protection of certain environmental amenities.

According to the common wisdom listed above, it is inappropriate to discuss disaster risk management of agriculture sector without putting it into the context of an economy. Models with multi-sector structure will be appreciated. Classical dual-economy model will be a nice choice to serve as the basic framework of discussion.

Agriculture disaster insurance: the puzzle

A main stream of research on agriculture disaster risk management is about its insurance. In many real cases and academic studies, it is specified to crop insurance other than cattle or fishery insurance. The word "puzzle" is used here because crop insurance against disaster based classical insurance theorem failed in many countries: few farmers are buying while few primary insurers are offering insurance coverage.

The discussion from Yokomatsu (2006, 2007) on insurance behavior of households in developing countries explains this problem to some extent. He firstly categorizes possible reasons into rational ones and irrational ones that hedge households from insuring their products/ income. If rural producers are assumed to be rational, then the loss that needs to insure must not be their prior concern. For instance, a) the income is just enough for feeding a household and it can not afford a insurance coverage package; b) disaster is not the only risk and probably it is not an important one; c) disasters threats the lives of household members that cannot be indemnified “monetarily” by insurance; or d) disaster insurance package is not attractive, either in terms of price or coverage level. Yokomatsu also touches upon irrational matters like a) the risk is not well perceived by households; or b) households have little knowledge on how insurance works to smooth its income.

Some articles qualitatively attribute the infeasibility of crop disaster insurance to the public goods feature of agriculture insurance (Tuo & Wang, 2002; Tuo & Li, 2005; Gao, 2006). The have claimed that, on the one hand, the marginal social benefit is larger than marginal personal benefit, from the side of the producers. As we know, stable supply of subsistence product is of substantial importance to economic development. If production of many crops increases is stimulated by the provision of crop insurance, the increase in the output, if the demand is assumed to be inelastic, will hurt producers but allow consumers to reap all the benefits (Hazell, 1981). In this sense, optimal demand of insurance coverage at the individual level must be lower than the social optimal level. On the other hand, although the consumption of a crop insurance contract is excludable, non-policyholders can take a free ride when there are some disaster insurance service provided to policyholders, e.g. disaster prevention education, early warning information or disaster mitigation measures provided by insurance companies. Due to the spill-over effect of disaster insurance service, marginal individual costs for providing crop disaster insurance is higher than marginal social costs. When both factors are taken into account, it is deduced that crop disaster insurance market will be inefficient and agriculture products will be under-covered, or there is no exchanging of contract in the market.

Some econometric studies (Bardsely, et al. 1984; Quiggin, 1986; Patrick, 1988; Fraser, 1988) have also touched upon this puzzle and their major conclusion is that crop disaster insurance is “too expensive” to afford for agriculture producers. When normal commercial loading factors are applied, premium required to keep low insolvent probability for insurers are sufficiently high to reduce the demand to zero. Only if implausibly low loading factors are assumed and farmers are highly risk averse are private markets for multi-peril crop insurance feasible. Of course a strong assumption for this hypothesis is that in reality insurance coverage is generally not divisible as it is not a continuous good as generally assumed in Economics textbooks.

It is necessary to know the composition of disaster insurance premium rate to tell why crop disaster insurance is described as “expensive”. Compared to other types of insurance, or even to other disaster insurance lines, loading factors of crop insurance is significantly higher. Firstly of all, agriculture disasters are generally of large scale but with medium frequency. Risks among policyholders are necessarily interdependent on each other. Secondly, administrative costs are extremely high, especially in developing countries where there are quite a number of producers living in vast rural areas. It happens in some cases that the cost for collecting premium from one household is even higher than the premium itself. Thirdly, inspection on moral hazard and disaster loss is quite expensive because of the same reason. Last but not the least, few catastrophic models are serving crop disaster insurance lines and the accuracy is far below than actuarial standard.

Subsidized Crop insurance: incentives and lessons

Direct government subsidy to crop insurance programs is now a popular policy instrument in countries where government initiatives are carried out to manage disaster risk in the agriculture sector. It is a typical inter-sectoral approach for the direct monetary transfer paid from tax-payers to agriculture producers. According to a systematic review by Skees et al. (2005) and Ibarra and Skees (2007), the subsidy is a kind of bilateral subsidy system: on the one hand, government subsidize premium that are a percentage of total premium while administrative costs of insurance companies are absorbed by government funds on the other. It is hoped that direct subsidy can work to establish a viable private crop disaster insurance market.

There are two major streams of hypothesis advocating that direct government subsidy to crop disaster insurance is necessary. The first one mainly corresponds to second hypothesis of crop insurance market failure mentioned in the previous section. If the marginal individual benefit of insuring crops against disaster risks is smaller than marginal social one, then producers should be compensated so that they increase their coverage to the social optimal level. Simultaneously, insurance companies should be compensated for their costs so that marginal individual costs for provision goes down to marginal social ones. This hypothesis seems applausive, but actually it has not been verified in a rigorously analytical manner as issues concerning the welfare economics of crop insurance are rarely discussed (Siamwalla and Valdes, 1986). Meanwhile, empirical works from Federal Crop Insurance Program (FCIP) of the United States show some result that does not necessarily support this hypothesis. Estimates of price elasticity of demand of crop insurance range from -0.2 (Barnett et al., 1990) to -0.90 (Gardner and Kramer, 1986) and there are several values in between (Goodwin, 1993; Smith and Baquet, 1996), which implies that producers' insuring behavior is not sensitive to premium subsidy and the marginal subsidy costs for enrolling additional buy-up acres have increased as subsidy levels have increased (Glauber, 2004). Even if the direct subsidy is justifiable, the costs will be substantially high (in year 2003, subsidy reaches to considerably 2 billion USD vs. 1.39 billion premium paid by producers covering 217.4 million acres of crops) and it is not convincing that the government can have all things done at a lower cost than private insurance companies. Meanwhile, the result "consistently confirms that low risk producers have a more elastic demand" and "only very low-risk producers, however, are found to have an elastic response to premium changes" (Goodwin and Smith, 1995). In this sense, Skees (1999) believes that "the risk subsidy makes society neither more efficient nor more equitable".

An alternative explanation of the government subsidy is from the viewpoint of political economics that programs redistributing economic welfare from taxpayers to agriculture producers are to "garner political support" (Goodwin and Smith, 1995). This hypothesis is founded by the seminal work of Becker (1983): pressure groups provide incentives in the form of votes to politicians who supply policy-generated income transfers to ensure the continued political support of their consistency. A group that becomes more efficient at producing political pressure would be able to reduce its taxes or raise its subsidy. Meanwhile, politically successful groups tend to be small relative to the size of the groups taxed to pay their subsidies. For instance, agriculture is heavily subsidized when a small sector as in Japan or U.S. but heavily taxed when a large sector as in Poland, China or Thailand. Dixit and Londregan (1995) discusses the phenomenon that declining industries in an economy, like the agriculture sector in many countries, are often subsidized instead of encouraging the movement of resources to other more productive uses, which is believed to be inefficient. They believe that such kind of redistributive policy is to keep dynamic consistency of the behavior of political parties and voters. Acemoglu and Robinson (2001) extended Becker's theory in a similar way, claiming that "when political institutions cannot credibly commit to future policy and when the political influence of a group depends on its size, inefficient redistribution is a tool to sustain political power". Thus, according to this theory, proportional subsidy to crop insurance premium is likely to be a tool for politicians to maintain their political support from agriculture producers. Empirical results confirm that "…when district are ranked according to total indemnity and disaster relief payments, the top ten U.S. congressional districts accounted for over 46 percent of the total taxpayer losses…" and it is also believed that benefits from disaster relief programs had been heavily concentrated in a small number of congressional districts (Goodwin and Smith, 1995).

2.1.4 Inter-temporal disaster risk diversification

Inter-temporal disaster diversification: theoretical basis

Yaari (1976) has firstly proved inter-temporal diversification of income risk for the first time by introducing uncertainty into Freidman's permanent income model. Suppose each household has a concave instant utility function with respect to consumption, which is a function of instant income of that period. Incomes of households are randomly determined period by period following some redistribution function. A household is able to utilize the credit market without any constraint to adjust its instant income for consumption through lending or borrowing. Households try to maximize expected lifetime utility. The result of the model implies that the expected value of consumption in the next period depends on the entire distribution of earnings and on the exact shape of the utility function, when the lifetime of households are limited. If the number of periods trends to infinite, optimal consumption tends to permanent income (mean of the redistribution), regardless of the distribution of earnings or the shape of the utility function. Simply saying, when households have unlimited lifetime and there is no constraint of lending or borrowing, their optimal choice is to smooth consumptions across time periods.

Such kind of buffer-stock strategy has further been discussed by Deaton (1991) and Gollier (1994, 2003b). In Gollier's model, he designed four market structures to discuss individuals' saving and consumption behavior in the face of uncertain cash in-flow (10 percent chances to lose 75% of the yearly income). When there is neither credit market nor insurance market, an individual consumes 77% of yearly income. When there is a spot insurance market with a 30% loading factor, there is an optimal deductable of 12% and the average consumption goes up to 90.4% of the annual income. When the credit market opens and individuals are requested to maintain positive balance of financial reserves, they shall keep a target financial reserve of 272% of annual income. The average buffer stock equals 159%, optimal deductible goes up to 63% and certainty equivalent consumption rises to 91.2% of annual income. The last structure is a credit market with fully efficient access to diversify risk across years but no insurance is available. In this structure, consumers keep a reserve level of 313% of annual income with certainty equivalent consumption of 90.6%. By comparing the results of four cases, it is believed that easing lending and borrowing constraints helps inter-temporal diversification of risk which can even dominant the effect of spot insurance contract.

Inter-temporal disaster diversification: why the state?

Inter-temporal diversification is a good way to finance disaster risk as the time of arrival of disasters is not necessarily mutually dependent of each other. Although the arrival of catastrophic disaster creates peak losses in certain periods, once the distribution of the arrival is known, inter-temporal approaches can be employed to smooth the peak shocks and the risk is then diversified. In this sense, the effect of diversification will be much better than inter-regional one as catastrophic disasters are affecting a large number of policyholders who are probably in a same pool.

The problem is that who can manage to diversify disaster risk across different time periods maximally, households, insurance companies, or the state government? The theory is proved with individual households but obviously it is not possible in reality. Individuals have limited lifetime and their credit in the market is also quite limited. The effect will not be very significant if the inter-temporal instrument is applied at individual level.

The discussion is controversial for insurance companies. Insurance companies have been supposed to adopt buffer-stock strategy to smooth yearly cash flow. What they need is a large pool of liquid capital through premium accumulation and business surplus which cushion the large random shocks and keep positive balances. The fact is that insurance companies are not able to maintain such kind of efficient and liquid reserve for the coming shocks. If the reserve is built up in the form of liquid cash, then insurers will face challenges from accounting practice in property/casualty insurance and tax systems, as well as the risk of taken-over (Jaffee and Russel 1996). It is not advocated by modern corporate finance theory to keep a large financial reserve, too.

If the reserve is set up as short-term liquid investment, then the profitability of the company cannot be guaranteed. Last but not least, the inefficient bridging between the primary insurer and the international reinsurer (Guy Carpenter & Company, 2007; Cummins, 2007), and between the insurance market and the capital market (Cummins and Danzon, 1997; Cummins and Doherty, 2002; Cummins, 2008) substantially reduces financial resources that an insurance company can use and consequently its capacity of diversification is sharply discounted.

In practice, inter-temporal diversification pools operated at the national level will be a better choice, as central governments are generally believed to be of little credit risk, sufficient liability and long survival period. The central government also has power in a centralized economy to redistribute the wealth in the society and balance citizens' welfare. Moreover, governments have easier access to low interest loans to smooth the shocks along the time. The best way to do this will be to ask the state to play the role of reinsurer of last resort, a backstop, by offering reinsurance contracts with a deductable corresponding to the capacity of the insurance company (Gollier, 2003b).

2.2 GOVERNMENT INITIATIVES OF DISASTER RISK DIVERSIFICATION

2.2.1 Subsidized crop disaster insurance in China

History of crop insurance in China

In the vast rural areas of China, agriculture production has been significantly suffering from natural disasters a lot. Tropic cyclones in the southeast coastal provinces, floods in major river basins, and drought in the vast Northern China and hilly areas of Southern China have been doing huge damage to agriculture production. The past ten years has been a decade with intensive arrival of large scale catastrophic events e.g. the floods in 1998, catastrophic typhoons in 2006 and 2007, and catastrophic snow in Central and South China in 2008. Due to the high vulnerability of Chinese rural and agriculture areas, large numbers of famers lose their yields year by year.

In Chinese Mainland, there was agriculture insurance program from the mid of 1980s to the late 1990s. The program encountered all problems that common disaster insurance would face. It was a puzzle: farmers felt premium rates were too high to afford while insurers felt premium rates were too low to maintain the business. When it was stopped by the central government, the program was identified as "low insurance penetration with quite high indemnity claim ratio". The People's Insurance Company of China (PICC), a state-operated insurance company at that time, stopped services for agriculture production as agriculture insurance lines were the least profitable products: the annual average indemnity claim ratio was 87.2% (Shi, 2007), which is much higher than the profitable threshold around 70% (Gollier, 2003b).

The new phase: China Agriculture Policy Insurance Pilot Program (CAPIP)

The agriculture insurance program was re-picked-up by the Chinese government as a component of agriculture supporting system in 2004, with the word “agriculture insurance” written in the No. 1 Document of the Central People’s Government of China of that year. In 2006, the Government issued *Some Opinions of the State Council on the Reform and Development of the Insurance Industry*, which addressed the intention “to improve multi-layer agriculture catastrophe risk transfer mechanism and seek for establishment of agricultural reinsurance system sponsored by central and local governments” (The State Council of China, 2006). In the following year, six provinces, municipality, or autonomous region were chosen to initiate pilot programs in agricultural disaster insurance. Compared to the previous program which is purely market-based commercial disaster insurance, the new program involves strong government intervention with direct premium subsidy from government budget at four levels, including central, provincial, city and county. For this reason, it is called “Agriculture Policy Insurance”, as a contrast to commercial insurance.

CAPIP: incentives

The major concern of launching agriculture insurance with government direct subsidy is the balance between the need of increased food production and well-being of agriculture producers in rural China (Swiss Re, 2008). It is expected to work mainly in following aspects:

1) Agriculture insurance can stabilize income variance of agriculture producers induced by natural events (yield loss in crop production or cattle sickness/ death). It is one of the most important non-structural disaster mitigation measures to provide disaster insurance so that rural households/ producers can get contingent capital for survival as well as recovery in a rapid sense.

2) The government believes that it is one of the most efficient approaches to help the agriculture insurance market to emerge by providing direct premium subsidy to crop insurance. Obviously the hypothesis on the public goods feature of crop disaster insurance is adopted here to support this incentive.

3) Direct premium subsidy is expected to create incentives for rural producers to increase the production of crops. This incentive corresponds to the hypothesis of Hazell (1981). Currently a large proportion of young and skilled rural labors are seasonally migrating to urban areas to earn a higher standard of living, crop production is mainly finished by the aged or unskilled. Agriculture production becomes relatively a small part of rural household income and therefore the opportunity cost of agriculture production becomes high. Rural households are choosing to cut their production plan, which could probably do harm for the entire society.

4) Subsidized agriculture insurance is provided as one of the WTO exempted agriculture support measures to provide farmers with direct subsidy. According to the popular hypothesis about the role of agriculture and the feature of agriculture insurance, it is believed that it can take the place of price intervention to create similar incentives.

CAPIP: operational structure

The intervention is believed to have learned from agriculture insurance program of the North American, particularly from the experience of the United States. Issues in common of CAPIP are concluded as:

- Multi-peril insurance lines for crop plantations against rainstorm, flood, inundation, strong wind, hail, frost, and drought.
- Premium rates differ from 3% to 10% according to region, crops, and perils. Transaction and administrative costs are not embodied in premiums. Insurance lines are priced as non-profitable for insurers.
- Low premium coupled with low liability. The insurance contract only covers the physical cost of crops, including costs in seeds, fertilizer, pesticide, irrigation, machinery, and mulching film. Costs in labor forces are excluded.
- Programs are operated at the provincial level. The central government and provincial government subsidize 50% of the premium while local governments (city and county level) subsidize around 10~30%. Policyholders will pay the rest of premium.
- Provincial governments extract capital for catastrophic reserve from annual business surplus of agriculture disaster insurance lines. When catastrophic disaster hits and indemnity reaches to a certain threshold, provincial governments will use the liquid fund kept in the reserve to help insurance companies cap the losses.

Some important statistics of the operation in year 2007 in representative provinces and municipalities are listed in Table 2-1. According to government documents on the operation of CAPIP, the operational structure is depicted in Fig. 2-1 (Zhou et al., 2009), taking the case in Hunan Province as an example (the People's Government of Hunan Province of China, 2008).The figure is drawn by the author after carefully reading official documents. The operational flow of underwriting and subsidize one insurance policy is described as below:

1) PICC (People's Insurance Company of China) city/county branches are expected to send their products to farmers and persuade them to join the program. If they are convinced to buy insurance coverage, then they pay less than 20 percent of the premium. According to valid insurance contracts, the county government, represented by the Bureau of Finance (BOF), will pay 20 ~ 30% of the premium, directly to the county branch. In total premiums paid by policyholder plus local government subsidy add up to 40% of the total insurance premium.

2) According to premium collected and valid contracts, PICC applies for the premium that should be paid by the central and provincial governments. The central government, represented by the Ministry of Finance (MOF), pays 35% of the premium while the provincial government, represented by the Department of Finance (DOF), affords 25%. The total 60% of premium is then paid to PICC provincial branch. Nevertheless, there would be a 25% offset of premium extracted and kept as disaster contingent reserve by DOF. Finally there is actually only 35% of the premium

going from PICC provincial branch to the city/ county branches, which finally receive 75% of the premium revenue.

Table 2-1 Operation of six pilot crop disaster insurance programs in China in 2007

Items \ Provinces		Hunan	Jilin	Inner Mongolia	Xinjiang	Sichuan	Jiangsu
Insured crops		Rice and cotton	Corn, rice, soybean, tobacco, et al.	Corn, rice, and soybean	Cotton, corn, rice, soybean and wheat	Rice and corn	Rice, wheat, cotton, cole and corn
Perils		Rainstorm, flood, inundation, wind, hail, frost, and drought			-	Rainstorm, flood, inundation, wind, hail, frost, and drought	
Liability *(CNY/ Mu [a]/ production season)* **and** **Premium rate** *(%)*		Rice: 240 (basic[b] 5%, drought 3%, all 7%) Cotton: 300 (8%)	Corn: 200 (10%) Rice: 266.7 (8%) Soybean: 166.7 (8%)	Corn: 230 (10%) Wheat: 300(8%) Soybean: 170 (8%)	Cotton: 400(7%)	-	Discriminated premium rate according to risk mapping.
Subsidy rate	Central	50%	25%	25%	25%	25%	-
	Provincial		25%	50%	25%	25%	
	Local	>=10%	30%	10%	-	20%	
	In total	>=60%	80%	85%	>=50%	70%	>= 60%
Summary of 2007	Premium (*CNY*)	750 million	-	-	760 million	74 million	450 million
	Indemnity (*CNY*)	440 million	-	-	-	19 million	150 million

Note: a. 1 Mu = 6.667 Are; b. basic liability means all perils except drought.
Source: Shi (2007)

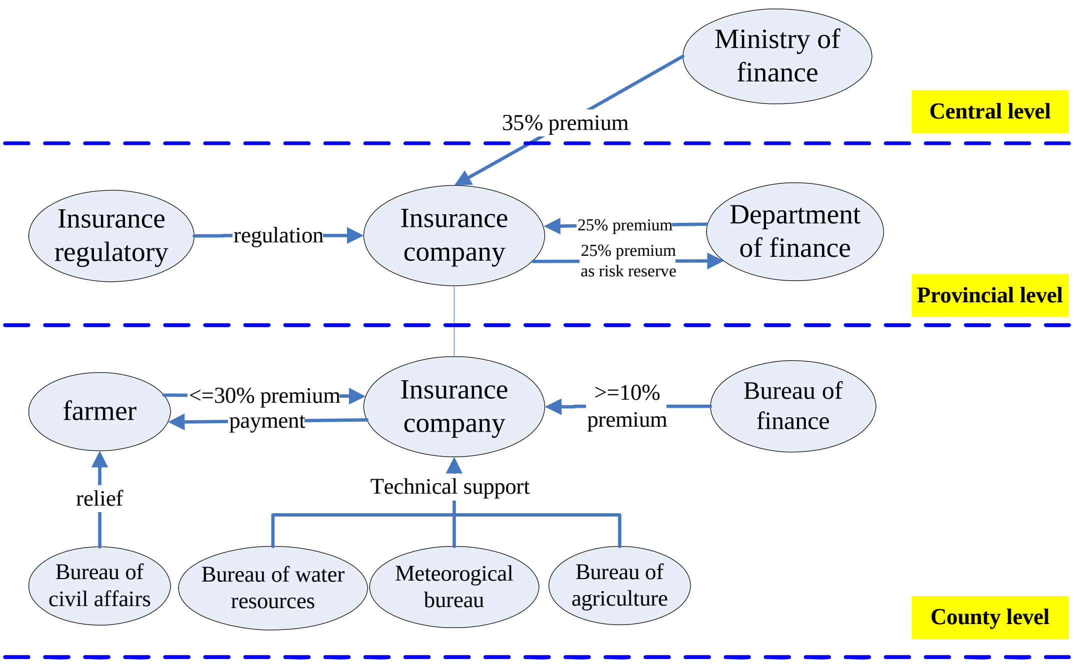


Fig. 2-1 Designed operational structure of the CAPIP (2008) taking PICC Hunan Branch as an example

CAPIP: Implementation at the local level

In order to check the operational details and implementation of the CAPIP at the local levels, the author conducted a field survey in July 2008 together with researchers from Beijing Normal University, China. The group visited seven cities/ counties in Hunan Province, Central China (Fig. 2-2), having workshop with local insurance company branches and face-to-face interview with rural producers.

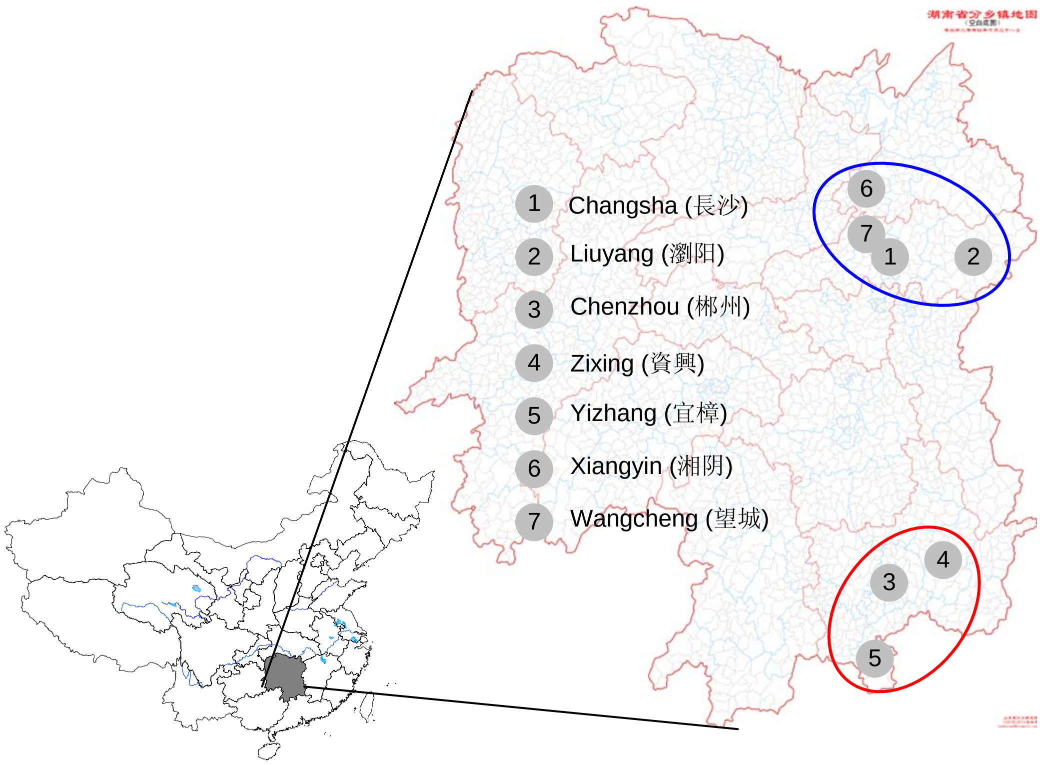


Fig. 2-2 Route of Field Survey on CAPIP

According to the records of workshops and households interview, the author believes that CAPIP has encountered following problems and challenges (Ye, 2008).

1) Objective difficulties in operating crop disaster insurance

a) The first issue is that rural households can correctly percept the risk but they have no idea about insurance, particularly crop disaster insurance. Consequently, rural producers' demand for disaster insurance is low. Insurance companies have to bear the costs in marketing to teach rural producers what is insurance and convince them that insurance is good for their livelihood.

b) Similar to all kinds of disaster insurance, crop disaster insurance lines of the CAPIP faces the problem of actuarial pricing. There are no convincing and valid disaster models supporting the pricing. Meanwhile, the length of historical indemnity data is quite short. Managers of crop disaster insurance lines can tell a range of the stop-loss premium rate according to the experience they have accumulated. It is believed that the pure premium rate should be ranging between 11~15%.

c) The transaction costs in administrative operation, premium collection, and losses inspection are so high, which actually has been pointed out by Ibarra and Skees (2007). In less developed countries where agriculture is still a labor-intensive sector, policyholder-based transaction costs are high enough to deprive the space for the market to emerge. For instance, in Liuyang County whose total area is 5007 km^2, there are 972,000 mu rice fields belonging to 315,620 farming households. Compared to the huge number of potential policyholders, the budget of the PICC Liuyang Branch can only afford to hire 4 staffs plus 1 mini van to have everything done. As mentioned by one of managers of PICC, "the transaction costs for collective the premium for 1 mu rice field is even higher than the premium itself (5.40 CNY)".

2) Institutional failures

a) Mandatory power goes beyond the scope of guidance and encouragement. Through the workshop with provincial branch of PICC, it is found that provincial government has been involved in the process of pricing insurance lines. Premium rates are actually determined by the negotiation between the Department of Finance of the provincial government and the PICC Hunan Branch. The rate is almost 5% lower than the empirically estimated one by insurance managers. Meanwhile, in 2008, the provincial government expands the scope of insurance liability in the negotiation. In this sense, the CAPIP is no longer market-mechanism-oriented.

b) Implementation at the local level violates the design of household-based and voluntary-based insurance. From the view point of local governments, it is relatively the easier way to have rural producers insured in a group-based and compulsory manner to reach the assigned participation rate by its higher level of government. As for insurance company branches, they are also glad to adopt the group-based and compulsory approach to save transaction costs which is attached to household-based operation. For this reason, insurance products and services do not really reach to the end-users. Information asymmetry increases the risk of fraud and corruption.

c) The institutional design has not successfully united stakeholders in implementing CAPIP. The motivation and concerns of central and local governments are different. The viewpoint and interest of provincial and local branches of insurance companies are also different. The inconsistency of motivation of stakeholders in operating CAPIP distorts the operation structure at the local level and the insurance cannot really work for rural producers.

2.2.2 Earthquake disaster insurance and reinsurance in Japan

Japan is a country located on the Circum-Pacific seismic zone. In history, Japan experienced several devastating earthquakes, including the well known Great Kanto Earthquake in 1934 and Hansin-Awaji Earthquake in 1995. In order to finance the huge damages induced by earthquake, the national earthquake insurance system of Japan was launched in 1966 and developed and improved during the past years. The system has been regarded as one of the most successful catastrophic insurance programs in the world, and numbers of reports and papers have investigated and discussed on this system. Therefore, this section will not go through the general matters repeatedly but pick up the essential pieces of information which highlights the contribution of Japanese government in this system.

The major role of the Japanese government in the national earthquake system in terms of financial aspect is a reinsurance partner. The earthquake insurance and reinsurance market in Japan consists of three layers. In the first layer, policyholders purchase insurance coverage from private insurance companies. The liability of primary insurers is then completely reinsured by Japan Earthquake Reinsurance Company, Ltd. (J.E.R.). In the third layer, J.E.R. cedes its liability to both private reinsurers and the Government. According to the latest revision in April 2008 (NLIRO, 2008), the liability sharing scheme between the J.E.R. and Japanese government is given as below (Fig. 2-3).

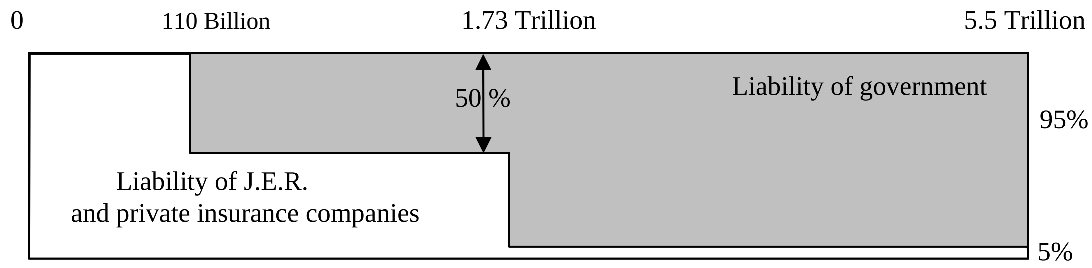


Fig. 2-3 Liability sharing of insurance companies and Japanese government

Sources: NLIRO (2008)

- For claims below 110 Billion JPY (induced by a single earthquake), Japanese government is not involved in sharing; for claims between 110 Billion and 1.73 Trillion JPY, insurance companies and Japanese government shall each bear 50% of the loss; for claims between 1.73 Trillion and 5.5 Trillion JPY, the Government shall bear 95% of the loss while the remaining is born by insurance companies.
- Until the Aggregate Limit of 5.5 Trillion JPY, the liability of J.E.R. and private insurance companies adds up to 1.1085 Trillion JPY while the Government will have to bear up to 4.3915 Trillion JPY. In case the insurance claim exceeds the up limit of 5.5 Trillion JPY, the respective insurance claims can be reduced and paid in accordance with the proportion of the Aggregate Limit to the total amount of insurance claims to be paid.
- Both insurance companies and the Government are obligated by the law to accumulate premium as liquid reserves, excluding the portion of necessary expenses for contracts. Additionally, it is obligated that all the investment profits from the accumulated liability reserves also be accumulated as liability reserves.

Moreover, concerning with the contribution of Japanese government and the money from the tax-payer, the premium rate of earthquake insurance is tightly tailored. The premium rate is determined as non-profitable for primary insurers while transaction costs are embodied in, including costs in administration and underwriting. A new discriminated premium rate system was adopted since 2007 and premium rates are given based on administrative divisions of "To-Dou-Fu-Ken". This update further reduces the costs for adverse selection and *ex ante* moral hazard.

The national earthquake insurance program could be highlighted in following aspects, according to the discussion of inter-temporal disaster risk diversification: 1) the insurance pool is set up at the national level. With the participation of the Government, risk units from different regions of the country and different generations are pooled simultaneously, which largely increases the effect of diversification across regions. 2) Credit of the state booms the capacity of financial reserve so that inter-temporal diversification will be very effective and further strengthens the confidence of the private sector in operating earthquake insurance.

Chapter 3

Labor Mobility, Goods Tradability, and Inter-sectoral Allocation of Disaster Risk

3.1 OUTLINE OF THIS CHAPTER

This chapter starts the discussion on disaster risk financing and resource allocation between economic sectors, which is to be finished in subsequent three chapters. The entire discussion is put in the context of rural China where the Chinese government is carrying out plenty of policies regarding farmers' income, agriculture production, and agriculture disaster risk management. The major component of policy instruments is to make direct or indirect financial transfer from tax-payers to the agriculture producer, a typical intervention approach regarding inter-sectoral resources as well as risk allocation.

The problem specifically addressed in this chapter is the efficient allocation of resources (labor) and disaster risk-bearing between rural and urban sectors. It describes a stylized economy in which a population of labors chooses their place to work between two sectors in two regions. The major issue is to answer under which circumstance(s) the migration behavior should be encouraged or discouraged by the central government to achieve economic efficiency in terms of resources and risk-bearing allocation. The major uniqueness of this stylized study includes: 1) It describes an *ex ante* and "circular" migration (Hare, 1999; Zhao, 1999a) of rural labors which is not easily seen in countries other than China and makes essential difference to existing works; 2) It incorporates collective risk concept into the model and tests the efficiency performance of the M.A. insurance system in a framework with potentially mobile labors; 3) Goods tradability is taken into account in the form of shipping costs per unit of goods.

Beyond the role as an independent chapter in this thesis, this chapter also provides the basic context and the general framework for the models in Chapters 4 and 5. It is important to have the basic assumptions in mind so that models in Chapter 4 and Chapter 5 can be understood in an easier way.

This Chapter is organized as follows: Section 3.2 introduces key assumptions applied in this model, including the context of the model regarding the situation in rural China, *ex ante* and circular migration, and land tenure system. In section 3.3, benchmark equilibrium is derived and comparative statics are employed to describe basic mechanisms of allocating risk and resources in the model. In section 3.4, social optimal choice on redistribution of wealth and allocation of disaster risk is derived as the criteria for evaluating efficiency performance of decentralized equilibira. In section 3.5, Malinvaud-Arrow (M.A.) insurance (first-best insurance) is introduced into the model as an alternative of the centralized approach. Benchmark equilibira, social optima, and M.A. insurance Equilibria are then compared in section 3.6 to answer the question raised above. Further discussion is put forward on optional intervention approaches for the central government to improve the efficiency of risk allocation achieved via the disaster insurance market. In the final section, the model is concluded and some discussion is put forward on policy implications as well as further research topics.

3.2 MODEL ASSUMPTIONS

3.2.1 The context of the model

In face of uncertainty in agriculture production and fluctuation in market price(s), more and more Chinese farmers are choosing to get accessed to off-farm income sources to get higher and more stabilized income, by working in non-farming sectors either locally or in regional large cities. The large labor flow in China started in the mid-1980s after the relaxation of long-standing controls over rural-urban migration (Zhao, 1999). In 2008, the number of urban labors migrating to the rural area reached 16.4 million, taking up of 22.6% of the total rural population (population with status of “rural resident”, *Nongcun Hukou*, in the household registration system) (State Statistical Bureau of China, 2009). Meanwhile, according to the author’s survey, many rural farming households are reducing their rice plantation plan so that more labor-hour can be allocated to off-farm jobs provided locally. The trend is believed to continue. In 2008, the annual average income of the urban household reached slightly more than 3 times of that of the rural household (BBC News, 2009), a critical value warned by the World Bank. Meanwhile, the institutional barrier of free rural-urban migration, the presence of household registration (*Hukou*) system, is getting weak. Investors are now investing more and more in rural areas to Township and Village Enterprises (TVEs) and there are more abundant locally off-farm job opportunities than ever before. Researchers are expecting even larger size of migration to urban areas and higher percentage of part-time farming in rural areas.

The impact of the rational choice of the farming household is revealed macroscopically. Grain production in China dropped significantly during the period of 1999 and 2003. In 2003, the aggregate output of grain is 431 million tons with a drop of more than 100 million ton from the one of 1998 (Statistical Bureau of China, 2008). The Chinese government does face some trade-off: migration and off-farm income sources can definitely help rural households increase annual income and reduce the size of rural-urban disparity, but it simultaneously reduces agriculture productivity and undermines foodstuff self-sufficiency of the country. Even worse, the drop mentioned above is with strict institutional control of migration with the *Hukou* system. According to Ito's simulation (Ito, 2008), the removal of the *Hukou* system would be accompanied by a massive migration to cities. In this sense, the Chinese government carries out a series of policies to increase incomes of rural household on the one hand and keep them in place on the other. These policy instruments include: 1) Give direct lump-sum subsidy to rural producers who do continue agriculture production, particularly grain plantation. 2) Conduct penalty to rural households whose crop land are left uncultivated. 3) Launch agriculture disaster insurance program and simultaneously give direct subsidy to insurance premium. 4) Give direct lump-sum subsidies to producers who purchase farming mechanisms to encourage technical progress. 5) As experiment, allow free transfer of land use right in some regions since 2008.

3.2.2 Factor mobility of the Chinese rural economy

Labor mobility

The rural-urban migration in China can be highlighted in the following aspects:

The move is ex ante: Chinese farmers start to move to urban areas right after the Chinese New Year, which is ahead of the planting season. They work in large cities for a whole year and return to their hometowns when the festival comes again. Since the model is concerned with the disaster(s) that happen(s) during the process of production, we call it "*ex ante*" migration. The motivation of migration is purely seeking for higher and more stable income provided by production activities other than farming. It is distinguished from the popular *ex post* migration structure in works of this field, in which labors migrate after random shocks have happened.

The move is seasonal and temporary: Due to the existence of household registration (*Hukou*) system, it is very difficult to change one's status from "rural resident" to "urban resident". Most migrants leave the families behind, return to them during periods of holiday or unemployment, and seldom assimilate with the urban population (Zhao, 1999a; Zhao, 1999b). Meanwhile, they retain the right of using one piece of land even when they are working in urban sectors. Due to this structure, the model is described basically in a static manner as the "migration" is actually seasonal move which repeats from one year to another.

The move is unidirectional: currently there is no evidence showing that urban residents are moving to work in rural sectors in China.

The migration is costly: According to empirical works, transaction costs engendered in the process of migration can be classified into two categories: monetary costs and physiological disutility. The first category refers to the costs in travelling, getting job permission, and hunting for a job, which explains around 30% of the total rural-urban wage gap (Zhao, 1999b). The second category refers to the disutility induced by being away from families, poor quality of housing, limited local service to migrants, and so on. This type is not directly observable. In the model, the transaction cost in migration is represented by lump-sum transaction costs, which refers to the monetary costs in migration. Furthermore, it is assumed that all seasonal workers can get jobs in the urban sector. Unemployment is popular in inter-regional migration models (e.g., models of Harris-Todaro type) but is not taken into account in this model since it is more concerned with disaster risk rather than unemployment.

For more information on the labor mobility of Chinese economy, review papers or reviewing part of technical papers will be useful for readers, e.g. Carter (1997), Yang (1997), Zhao (1999a), Zhao (1999b), Hertel and Zhai (2006), Ito (2008).

Rural land tenure system

The land tenure system is another important aspect of factor mobility with respect to risk management related to agriculture sector. In rural China, land for agriculture production is owned by the "collective" while the "use-right" is allocated to farming households, which was prohibited to transfer, in the forms of lease, selling, or auction. Although the system started to change in some parts of Mainland China as pilot programs since 2008, it has not become the mainstream yet. When a household leaves for urban areas for a seasonal job, it retains the use-right and asks someone else for a favor e.g. friends, relatives, or neighbors, or makes some informal contract with other household, to cultivate the land for it. This situation happens partially because otherwise the severe penalty could even deprive the right of using that piece of land. In this model we adopt simple assumption that the land is left uncultivated if the "user" goes to the urban sector, for the sake of simplicity. In this sense, factor mobility in this model refers only to labor mobility.

3.2.3 The structure of the model

Consider a small closed economy with two regions and two sectors, both rural and urban. The rural sector is in the rural area, producing the so-called rural goods while the urban sector is in the urban area and produces urban goods. Rural goods are only used for private consumption while urban goods are used for private consumption as well as capital investment. The production processes in both sectors are assumed to be exposed to natural disasters. There is a population of totally N labors in this economy, among which N_1 labors residing in the rural area and N_2 residing in the urban area. Labors are assumed to be homogeneous in terms of natural endowment, including the quality of human capital for all residents and agriculture land for rural residents. An individual's welfare state is determined by his/her consumption on both kinds of goods.

The symbol system used in Chapters 3, 4, and 5 are listed as below. Symbols represent the same meaning throughout the three Chapters unless stated specifically in the text.

N, N_1, N_2	Total population, population of rural residents, and population of urban residents
n	The number of seasonal workers
s	Individual state of the rural worker
t	Collective state of the small world
$\pi(\cdot)$	The probability of a certain state being chosen
$X(\cdot)$	Output of rural goods of a certain rural worker, contingent on the state
$\mathrm{EX}(t)$	Per capita output level of rural goods, contingent on the collective state
$Y(\cdot)$	Production function of the urban sector
c	Transaction costs for the seasonal move
δ_i	with $i = x, y$ representing the costs for shipping rural goods and urban goods, respectively
x	The consumption of rural goods
y	The consumption of urban goods
$p(t)$	The relative price of rural goods to urban goods, contingent on the collective state
$u(x, y)$	*Ex post* direct utility function
ϵ	Elasticity of substitution between the rural goods and the urban goods
$v(\cdot)$	*Ex post* indirect utility function (maximized utility function), contingent on the state
$A(t)$	Coefficient associated to economic value of goods in the indirect utility function
$W(\cdot)$	*Ex ante utility* function following CRRA preference
$B(t)$	Social aggregate urban goods available for consumption, contingent on the collective state
$\Omega(t)$	Social aggregate economic value of goods for consumption, contingent on the collective state
$\omega(\cdot)$	Individual economic value of goods for consumption, contingent on states
$w(t)$	The labor income of urban workers, contingent on the collective state
$e(\cdot)$	Labor income (initial endowment), contingent on states
ρ	The proportion of individual economic value of goods for consumption to the social aggregate one
E	Expectation operator
γ	Subject weight allocated to a certain individual group by the central planner
$m(s, t)$	Mutual insurance coverage against a certain joint state (*s*, *t*)
$a(t)$	The demand of the Arrow security against a certain collective state *t*
$r(t)$	The price of the Arrow security against a certain collective state *t*
τ , χ	Lump-sum transfer of wealth, either tax or subsidy
$R(t)$	Mandatorily determined price of Arrow security under government intervention

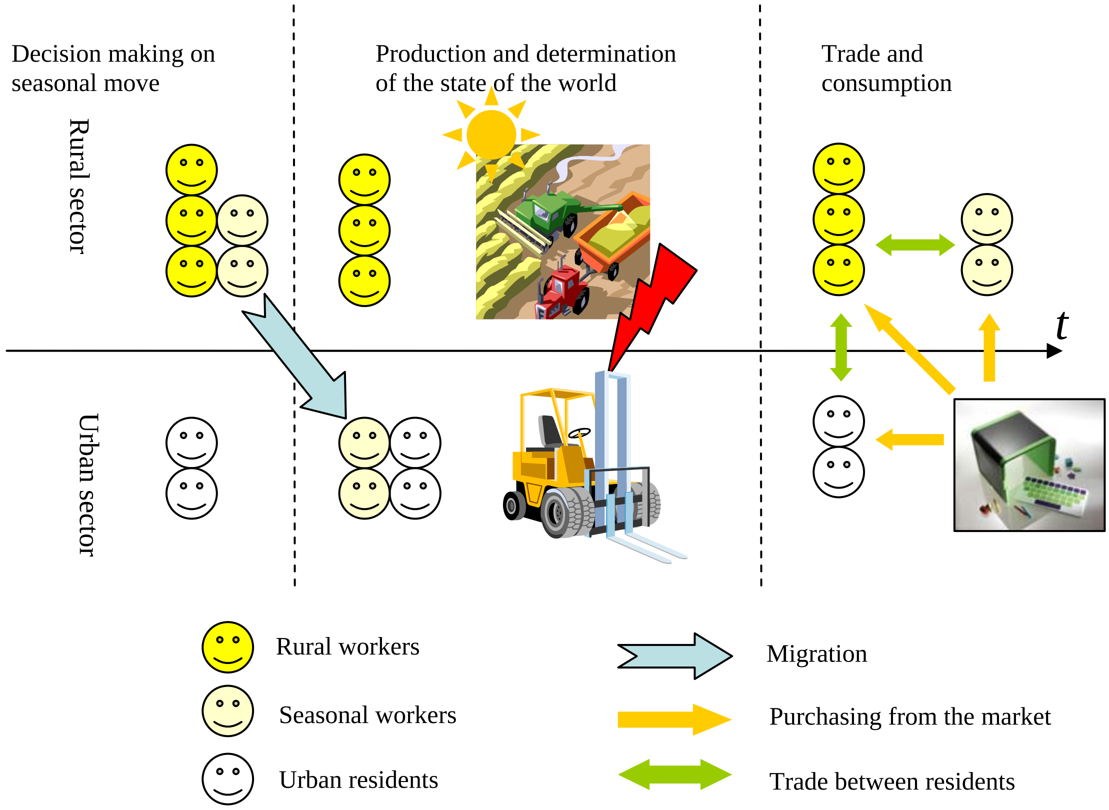


Fig. 3-1 Event sequence of the model

The time sequence of events in this model is described as below according to Fig. 3-1:

Decision-making on seasonal move

At the beginning of each period, rural residents consider whether to move to the urban area or not. If they decide not to move, they cultivate their land and are then called “rural producers” (farmer is a special case). If they decide to move, they will work in the urban sector and then are called “seasonal workers”. Therefore, before the seasonal move starts we have two groups of individuals: rural residents and urban residents. After that, we have three groups of individuals, rural producers, urban residents and seasonal workers, which are given subscripts of 1, 2 and 3 in the following part of this chapter, respectively.

Production process

In this phase, workers start to produce goods. Rural producers produce the so-called “rural goods” on household basis. Since they do not have any other investment or production alternatives, we assume that each rural producer contributes inelastically one unit of labor in production, which is assumed to be an optimal amount. This assumption stands in this model as our focus is rural-urban migration rather than on-farm decision-making. If no uncertainty is taken into consideration, rural producers will exactly produce the same amount of output, X. When disaster risk is taken into account, the final production becomes a function of the state of the crop land, $X(s)$, in which *s* is a random variable denoting the state of that piece of land.

In the urban sector, production is made in an aggregate manner with a function of $Y=Y(K,L)$, in which *K* denotes the total social capital stock for production and *L* denotes the total labor force engaged. The wage rate is determined by the marginal productivity with respect to labor, $w = \partial Y(K,L)/\partial L$. It is assumed that the technology in the urban sector is constant-return-to-scale with respect to labor input, $\partial^2 Y(K,L)/\partial L^2 = 0$ and w is a constant. This assumption excludes the possibility of externality induced by technology and helps us to catch the essential impact from labor mobility and goods tradability. Here an urban worker's decision-making on his working hours is also skipped by assuming that there is mandatorily designated official working hours, e.g. 8 hours/day. This can be further simplified by unifying working hours to 1. Thus the labor income for an urban worker is exactly w.

The move to urban area is costly. Rural residents who move to work in urban sector are supposed to pay a lump-sum cost, denoted by c, for the move. For the sake of simplicity, we allow seasonal workers to pay this cost after wages are paid. So the actual income for a seasonal worker is $w-c$.

Disaster and the state of the world

In this model the production of both sectors is exposed to natural disaster risk, which is framed with the collective risk theory introduced in Section 2.2. Firstly, the nature chooses the size, geographical location, and severity of the hazard, determining the collective state of the world $t \in \{0,1,\ldots,T-1\}$. As for individual states, in accordance to our assumption on production functions, we assume that rural production activity could fall in different individual states and consequently rural producers may have different harvesting after some disaster events $X(s)$, $s \in \{0,1,\ldots,S-1\}$. On the other hand, the entire urban sector falls into some same state as it is assumed to be a "big" company and all urban workers will have uniform *ex post* income $w(t)$. In other words, individual states of urban workers coincide with the collective states of the world.

It is worth noting that the risk units here are not workers but plots of land. The probability for a piece of land being in a joint state (s,t) is given by $\pi(s,t) > 0$, with $\sum_{s,t} \pi(s,t) = 1$. So the probability of the production of a specific plot of land with output of $X(s)$ could be derived as the conditional probability of $\pi(s \mid t) = \pi(s,t)/\sum_{s'} \pi(s',t)$. Then exactly there would be $\pi(s \mid t) \cdot N_1$ pieces of land in individual state *s* when collective state *t* occurs. When seasonal move is taken into account, the total number of cultivated land reduces by *n*, the same as the number of seasonal workers. The theorem, although not perfectly appropriate, still applies when it is assumed that the land of seasonal workers is distributed uniformly in the space. In this sense, the number of cultivated but damaged land in the joint state of (s,t) is $\pi(s \mid t) \cdot N_1 \cdot (N_1 - n)/N_1$ = $\pi(s \mid t) \cdot (N_1 - n)$, while the social aggregate output of rural goods is $\sum_s \pi(s \mid t)(N_1 - n) X(s)$ $=(N_1 - n)\mathrm{EX}(t)$.

Trade and consumption

Consumption of workers starts after the state of the world is known. It is assumed that all workers have homogeneous preference, $u_i = u(x_i, y_i)$, for *i*=1,2,3 denoting rural producers, urban residents, and seasonal workers, respectively. As rural goods are produced individually, rural producers firstly reserve a certain amount of rural goods x_1 for consumption, and then sell the surplus $X(s) - x_1$ to the market. This type of setting mainly refers to the so-called "subsistence agriculture" or "self-sufficiency agriculture": rural producers guarantee their consumption with priority. In commercial agriculture, farms sell all yields to the market. Workers of the farms earn wages from farms and then go to the market to purchase goods for consumption. For more detailed discussion on this point, please refer to the discussion on subsistence agriculture (Kostov and Lingard, 2004). Goods tradability is taken into account at this stage, which is represented by lump-sum costs for shipping goods between regions. Transaction costs for delivering per unit of rural and urban goods are δ_x and δ_y, respectively. If the relative price of rural goods to urban goods in an arbitrary collective state *t* is denoted by $p(t)$, the budget constraints for workers are:

$$p(t)\left[X(s) - x_1(s,t)\right] = \left(1 + \delta_y\right) y_1(s,t), \text{ for all } s, t, \tag{3.1}$$

$$\left[p(t) + \delta_x\right] x_2(t) + y_2(t) = w(t), \text{ for all } t, \text{ and} \tag{3.2}$$

$$\left[p(t) + \delta_x\right] x_3(t) + y_3(t) = w(t) - c, \text{ for all } t \tag{3.3}$$

In the budget constraints, seasonal workers are supposed to pay δ_x instead of δ_y. It is because seasonal workers stay in the urban area almost all the time in a year except a few days for holidays at their hometown. The social budget constraints follow:

$$\sum\nolimits_{N_1 - n} \left[X - x_1(s,t)\right] - N_2 x_2(t) - n x_3(t) \le 0, \text{ for all } s, t \tag{3.4}$$

$$\sum\nolimits_{N_1 - n} y_1(s,t) + N_2 y_2(t) + n y_3(t) \le Y\left(N_2 + n\right) - C, \text{ for all } s, t, \tag{3.5}$$

in which *C* is the social aggregate consumption on transportation to move seasonal workers and costs for shipping goods between rural and urban areas. Since the model is basically in a static manner, dynamic investment decision is not essential to our discussion and therefore capital stock investment for production of the next period can be skipped. If we assume the economy is running at its steady state where the return to capital stock is fixed, with the assumption of constant-return-to-scale technology with respect to labor, social consumable urban goods can actually be denoted by $Y(N_2 + n) - C = (N_2 + n) w(t) - C$, which is exactly the difference between social aggregate wage paid to urban workers and social aggregate transaction costs.

3.3 THE BENCHMARK CASE

3.3.1 *Ex post* equilibrium

After the state of the world is determined, an individual tries to maximize *ex post* utility given the state-contingent wealth (or say "money" in terms of the urban good), $\omega_i(\cdot)$. In the benchmark case, it is equivalent to state-contingent labor income, $e_i(\cdot)$. As for the rural producer, the labor income equals the revenue of selling all products in hand. As for the urban worker, the labor income equals the labor wage. We assume that the *ex post* utility function follows Cobb-Douglas form (C-D) between the rural good and the urban good,

$$u(x,y) = \psi x^{\frac{\epsilon}{1+\epsilon}} y^{\frac{1}{1+\epsilon}}, \psi = \frac{\epsilon}{1+\epsilon}^{-\frac{\epsilon}{1+\epsilon}} \frac{1}{1+\epsilon}^{-\frac{1}{1+\epsilon}}$$

Here ψ is used to simplify the denotation of the indirect utility function. The utility function strictly follows that $u_x > 0 > u_{xx}$, $u_y > 0 > u_{yy}$, $u_{xy} > 0$. *Ex post* optimization implies that the marginal rate of substitution should be equal to the relative price, $u_x / u_y = P$, in which P is the subjective effective price for an individual. In this model, according to the budget constraint in (3.1), (3.2) and (3.3), the effective relative price for rural producers (subscript 1) and urban workers (subscript 2 and 3) are $P_1 = p(t)/\left(1+\delta_y\right)$ and $P_{2,3} = p(t) + \delta_x$, respectively. In this sense, optimal consumption bundles can be derived as:

$$\begin{aligned} x_1^*(s,t) &= \frac{\epsilon}{\epsilon+1} X(s), y_1^*(s,t) = \frac{p(t)X(s)}{(\epsilon+1)\left(1+\delta_y\right)} \\ x_2^*(t) &= \frac{\epsilon w(t)}{(\epsilon+1)\left(p(t)+\delta_x\right)}, y_2^*(t) = \frac{w(t)}{\epsilon+1} \quad \text{, for all } s, t \\ x_3^*(t) &= \frac{\epsilon\left[w(t)-c\right]}{(\epsilon+1)\left(p(t)+\delta_x\right)}, y_3^*(t) = \frac{w(t)-c}{\epsilon+1} \end{aligned} \tag{3.6}$$

The social excessive demand function can be constructed as:

$$Z_x(t) = \sum x_1^*(s,t) + N_2 x_2^*(t) + n x_3^*(t) - \left(N_1 - n\right)\mathrm{EX}(t) \text{, for all } t, \tag{3.7}$$

According to Walras' Law, the necessary condition for an efficient *ex post* goods market is $p(t)Z(t) = 0$, for all *t*. Since we assume both rural and urban good are not free goods, it must hold that $p(t) > 0$ and $Z(t) = 0$. Therefore:

$$p(t) + \delta_x = \frac{\epsilon B(t)}{\left(N_1 - n\right)\mathrm{EX}(t)} \text{, for all } t, \tag{3.8}$$

with $B(t) = N_2 w(t) + n\left[w(t) - c\right]$, denoting social aggregate urban goods available for consumption. Note that transaction costs for shipping goods are not excluded from $B(t)$. Equation (3.8) means that subject effective relative price for the urban workers equals to the elasticity of substitution times the ratio of the social aggregate production for consumption (*ex post* consumption on shipping goods in included) to social aggregate urban goods available minus the transaction costs for shipping per unit of rural goods. In this sense, individuals' optimal choices are derived by putting (3.8) into (3.6):

$$\begin{aligned}
&x_1^*(s)=\frac{\epsilon}{1+\epsilon}X(s),y_1^*(s,t)=\frac{\left[\epsilon B(t)-\delta_x\left(N_1-n\right)\mathrm{EX}(t)\right]}{(1+\epsilon)\left(1+\delta_y\right)\left(N_1-n\right)\mathrm{EX}(t)}X(s)\\
&x_2^*(t)=\frac{1}{1+\epsilon}\frac{\left(N_1-n\right)\mathrm{EX}(t)}{B(t)}w(t),y_2^*(t)=\frac{w(t)}{1+\epsilon} \qquad , \text{for all } s, t \qquad (3.9)\\
&x_3^*(t)=\frac{1}{1+\epsilon}\frac{\left(N_1-n\right)\mathrm{EX}(t)}{B(t)}\left[w(t)-c\right],y_3^*(t)=\frac{w(t)-c}{1+\epsilon}
\end{aligned}$$

It can be observed that only the consumption of rural producers is affected by goods tradability, given the fact that we are using urban goods as numeraire in this model. Following the optimal consumption bundle, *ex post* indirect utility function can be derived as:

$$\begin{aligned}
&v_1(s,t)=\left(\frac{1}{1+\delta_y}\right)^{\frac{1}{\epsilon+1}}\left(\frac{1}{p(t)}\right)^{\frac{\epsilon}{\epsilon+1}}\omega_1(s,t)=A_1(t)\,\omega_1(s,t)\\
& \qquad , \text{for all } s, t \qquad (3.10)\\
&v_{2,3}(t)=\left(\frac{1}{p(t)+\delta_x}\right)^{\frac{\epsilon}{\epsilon+1}}\omega_{2,3}(t)=A_{2,3}(t)\,\omega_{2,3}(t)
\end{aligned}$$

with

$$\begin{aligned}
\omega_1(s,t)&=p(t)\,x_1(s,t)+\left(1+\delta_y\right)y_1(s,t)\\
\omega_2(t)&=\left(p(t)+\delta_x\right)x_2(t)+y_2(t)\\
\omega_2(t)&=\left(p(t)+\delta_x\right)x_3(t)+y_3(t)
\end{aligned}$$

Equation (3.10) means that *ex post* indirect utility functions are linear systems with respect to state-contingent wealth for consumption (the total monetary resources that an individual used to consume). In this benchmark case, it holds that $\omega_i(\cdot)=e_i(\cdot)$. Following the same concept, social aggregate economic value of goods can be denoted as

$$\begin{aligned}
\Omega(t)&=\sum\nolimits_{N_1-n}\omega_1(s,t)+N_2\omega_2(t)+n\omega_3(t)\\
&=\sum\nolimits_{N_1-n}e_1(s,t)+N_2e_2(t)+ne_3(t) \quad , \text{for all } t \qquad (3.11)\\
&=(1+\epsilon)B(t)-\delta_x\left(N_1-n\right)\mathrm{EX}(t)
\end{aligned}$$

3.3.2 *Ex ante* equilibrium and comparative statics

We further assume that individuals' *ex ante* utility is a function $W\left(v_i(\cdot)\right)$ showing Constant Relative Risk Aversion (CRRA) preference:

$$W\left(v_i(\cdot)\right) = \begin{cases} \dfrac{v_i(\cdot)^{1-\theta} - 1}{1-\theta}, & \theta \neq 1 \\ \ln v_i(\cdot) & \theta = 1 \end{cases}, \text{ for all } s, t. \tag{3.12}$$

Expected *ex ante* utility then takes the form of $\mathrm{E}\,W_i = \sum_{s,t} \pi(\cdot) W\left(v_i(\cdot)\right)$.

Comparative statics show that $d\mathrm{E}\,W_1 / dn > 0$ while $d\mathrm{E}\,W_2 / dn, d\mathrm{E}\,W_3 / dn < 0$. When there are more seasonal workers and less rural producers, the total productivity of the rural sector decreases due to the outflow of labor forces. The relative price of the rural good consequently increases and rural producers' state-contingent wealth gets larger, given the fact that they are producing exactly the same amount of the rural good. We then see an increase in the expected utility of rural producers. In contrast, although we assume the technology is constant-return-to-scale with respect to labor for the urban sector and they shall get exactly the same salary, state-contingent wealth of urban workers will drop since the same amount of money in hand can purchase fewer rural goods as the price goes up.

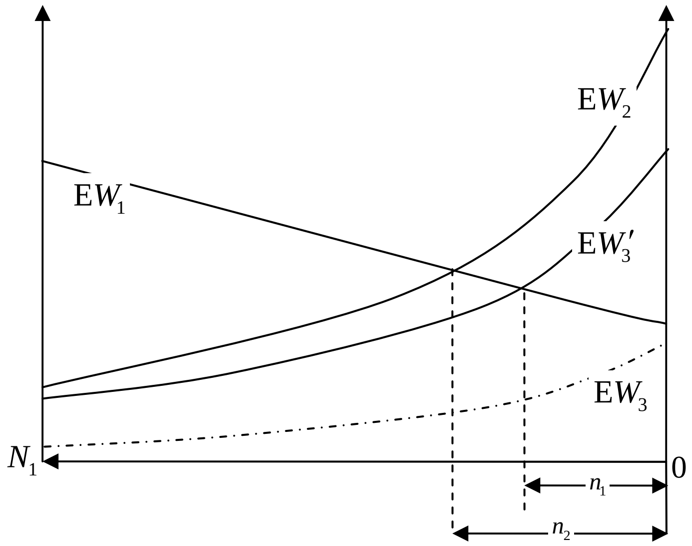
According to the assumption, a rural resident makes decision on whether he should conduct the seasonal move or not *ex ante*. Given the uncertain nature of the world, the decision is made by comparing the expected *ex ante* utility of working in rural sector and urban sector. A rural resident is willing to conduct the seasonal move iff $\mathrm{E}\,W_1 < \mathrm{E}\,W_3$ and the marginal seasonal worker will find himself exactly indifferent of working in either sector, which implies the *ex ante* equilibrium must hold:

$$\mathrm{E}\,W_1 = \mathrm{E}\,W_3 \tag{3.13}$$

In Fig. 3-2, the number of seasonal workers increases from the right hand side to the left, from 0 until N_1. The up-sloping curves from the left hand side to the right are used to denote $\mathrm{E}\,W_2$ and $\mathrm{E}\,W_3$ while the down sloping curve is used to denote $\mathrm{E}\,W_1$. From comparative statics we know that expected utilities show monotonic change with respect to the change in the number of seasonal workers. Therefore, for a given degree of mobility and tradability, we will find no more than one intersecting point of $\mathrm{E}\,W_1$ and $\mathrm{E}\,W_3$. This point then indicates the equilibrium number of seasonal workers of the benchmark case.

Labor mobility and equilibrium population distribution

In Fig. 3-2, labor mobility, the transaction cost *c* actually determines the gap between curves $\mathrm{E}\,W_2$ and $\mathrm{E}\,W_3$. When *c* is relatively high (e.g. the dash-dot line in the Fig. 3-2), seasonal move shall never occur because a rural resident will find himself definitely worse off to work in the urban sector as in this case $\mathrm{E}\,W_3$ lies everywhere below $\mathrm{E}\,W_1$. When *c* goes down gradually and the gap between $\mathrm{E}\,W_2$ and $\mathrm{E}\,W_3$ becomes narrower, $\mathrm{E}\,W_1$ and $\mathrm{E}\,W_3$ may intersect at some valid *n* (e.g. n_1 in Fig. 3-2). When *c*=0, rural residents would be free for the move and $\mathrm{E}\,W_2 = \mathrm{E}\,W_3$. Two respective curves in Fig. 3-2 overlap each other. The equilibrium number of seasonal workers is then located where curves $\mathrm{E}\,W_1$ and $\mathrm{E}\,W_2$ intersect each other (e.g. n_2 in Fig. 3-2).



c determines the gap between $\mathrm{E}W_2$ and $\mathrm{E}W_3$.

When c is too large (the dash-dot line in the figure), there would be no valid intersection point and thus seasonal move will not occur.

When c is moderate, $\mathrm{E}W_1$ and $\mathrm{E}W_3$ intersects at the point where $n=n_1$.

When $c=0$, $\mathrm{E}W_2$ and $\mathrm{E}W_3$ shall overlap and the number of seasonal workers would be n_2 in the figure.

Fig. 3-2 Household mobility and equilibrium population distribution

Comparative statics of the *ex ante* equilibrium with respect to factor mobility can be derived with the following approach. Define the implicit function of $n^*(c)$ by:

$$f\left(n^*, c\right) = \mathrm{E}\,W_1\left(n^*\right) - \mathrm{E}\,W_3\left(n^*, c\right) = 0$$

In this sense,

$$\frac{dn^*}{dc} = -\frac{f_c}{f_n} < 0$$

Consequently it holds that

$$\frac{d\mathrm{E}\,W_1}{dc}, \frac{d\mathrm{E}\,W_3}{dc} < 0, \frac{d\mathrm{E}\,W_2}{dc} > 0$$

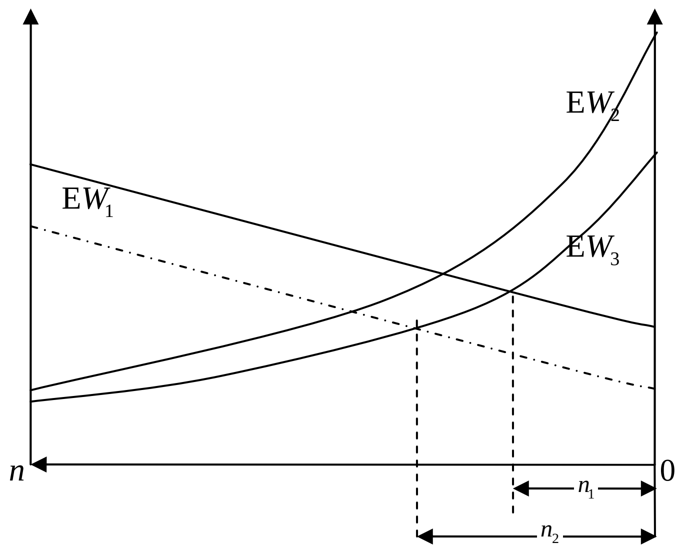
It implies that when transaction costs increase, expected utility of rural producers and seasonal workers decreases while urban residents get benefit. Less seasonal workers explicitly means that there will be more rural goods available for consumption in any arbitrary collective state and consequently state-contingent prices goes down. In this sense, rural producers' labor incomes which are equal to their product revenue go down and they get worse off. As for seasonal workers, they benefit from lower relative price but suffer from higher transaction costs. Unfortunately, effect of the later one is dominant so they finally get worse off.

Goods tradability and equilibrium population distribution

Compared to the labor mobility, goods tradability only determines the vertical position of $\mathrm{E}\,W_1$ in the figure, which can be observed from (3.9) that parameters δ_x and δ_y only appear in the optimal consumption bundle of the rural producer. Higher transaction costs in shipping goods corresponding to lower $\mathrm{E}\,W_1$ curve in Fig. 3-3 (e.g. the dot-down-sloping curve). As strictly monotonic functions, lower vertical location of $\mathrm{E}\,W_1$ implicitly implies larger equilibrium number of seasonal workers. If we assume the costs for shipping the rural and the urban goods are the same, $\delta_x = \delta_y = \delta$, comparative statics imply:

$$\frac{dn^*}{d\delta} > 0, \frac{d\mathrm{E}\,W_1}{d\delta}, \frac{d\mathrm{E}\,W_2}{d\delta}, \frac{d\mathrm{E}\,W_3}{d\delta} < 0 .$$

It means that the transaction costs for shipping goods will definitely induce social loss in terms of expected *ex ante* utility.



δ_x and δ_y determine the position of EW_1. The higher the value of δ_x and δ_y, the lower EW_1 locates in the figure, and the more rural residents become willing to conduct the seasonal move.

Fig. 3-3 Goods tradability and equilibrium population distribution

3.4 SOCIAL OPTIMUM

Consider the optimal risk allocation and population distribution problem in the society. The wise central planner is supposed to maximize the weighted sum of expected utility functions by dictating everything of the economy. Thus, the social optimization problem can be formulated as:

$$\max_{\substack{n, x_1(s,t), x_2(t), x_3(t) \\ y_1(s,t), y_2(t), y_3(t)}} U = \gamma_1 \sum\nolimits_{N_1 - n} \mathrm{E}\,W_1 + N_2 \gamma_2 \mathrm{E}\,W_2 + n \gamma_3 \mathrm{E}\,W_3 ,$$

in which γ_i denotes the weight allocated to individuals of type *i* by the central planner. The optimum is achieved through determining *ex post* redistribution of wealth for consumption and *ex ante* number of seasonal workers. In the previous section it has been proved that *ex post* indirect utility only depends on state-contingent wealth for consumption. Therefore, *ex post* redistribution of both rural goods and urban goods can be simplified to determining economic values of goods allocated to individuals, namely $\omega_i(\cdot)$:

$$\max_{n,\omega_1(s,t),\omega_2(t),\omega_3(t)} U = \gamma_1 \sum_{N_1-n} \mathrm{E}\,W_1 + N_2\gamma_2 \mathrm{E}\,W_2 + n\gamma_3 \mathrm{E}\,W_3,$$

subject to

$$\begin{aligned} \alpha(s,t) &: \sum_s \pi(s \mid t)(N_1-n)\omega_1(s,t) = \Omega_1(t) \\ \alpha(t) &: \Omega_1(t) + N_2\omega_2(t) + n\omega_3(t) = \Omega(t) \quad \text{, for all } s, t \\ \mu &: \mathrm{E}\,W_1 = \mathrm{E}\,W_3 \\ & n, \omega_1(s,t), \omega_{2,3}(t) \geq 0 \text{, for all } s, t \end{aligned} \tag{3.14}$$

Throughout this thesis, the Greek letter ahead of each constraint is its corresponding Lagrangian Multiplier. By assuming interior solutions, the first-order conditions with respect to state-contingent wealth can be derived as:

$$\begin{aligned} \left[(N_1-n)\pi(s \mid t)\gamma_1 - \mu\right]\pi(s,t)\frac{dW_1(\cdot)}{d\omega_1(s,t)} &= \alpha(s,t)(N_1-n)\pi(s \mid t) \\ \sum_{s'} \alpha(s',t) &= \alpha(t) \\ N_2\gamma_2 \frac{dW_2(\cdot)}{d\omega_2(t)} - \alpha(t)N_2 &= 0 \\ n\gamma_3 \frac{dW_3(\cdot)}{d\omega_3(t)} - \alpha(t)n + \mu\frac{dW_3(\cdot)}{d\omega_3(t)} &= 0 \end{aligned} \text{, for all } s, t \tag{3.15}$$

The first equation of the first-order conditions is equivalent to:

$$\left[\gamma_1\pi(s,t) - \frac{\mu\pi(t)}{N_1-n}\right]\frac{dW_1(\cdot)}{d\omega_1(s,t)} = \alpha(s,t) \text{, for all } s, t \tag{3.16}$$

If we sum up (3.16) across all individual states, it yields that

$$\pi(t)\left[\gamma_1 - \frac{\mu}{N_1-n}\right]\frac{dW_1(\cdot)}{d\omega_1(s,t)} = \alpha(t) \text{, for all } t \tag{3.17}$$

In (3.17), the marginal *ex ante* utility of the rural producer only depends on the collective state of the world. In other words, the redistributive policy of the central planner will diminish individual disparity and consequently all rural producers are allocated with the same amount of economic value of goods for consumption, $\omega_1(s,t) = \omega_1(t)$, for all s. In this sense, first-order conditions can be generalized to:

$$\frac{\gamma_1(N_1-n)+\mu}{N_1-n}\cdot\frac{dW_1(\cdot)}{d\omega_1(t)} = \gamma_2\frac{dW_2(\cdot)}{d\omega_2(t)} = \frac{\gamma_3 n-\mu}{n}\cdot\frac{dW_3(\cdot)}{d\omega_3(t)} = \frac{\alpha(t)}{\pi(t)} \text{, for all } s, t \tag{3.18}$$

Equation (3.18) implies that the allocation of wealth among individuals should equalize the weighted marginal *ex ante* utility across all individual types in a given collective state *t*.

The first-order condition with respect to the number of seasonal workers is:

$$\begin{aligned}
&-\gamma_1 \mathrm{E}\, W_1 + (N_1 - n)\gamma_1 \frac{d\mathrm{E}\, W_1}{dn} + \gamma_3 \mathrm{E}\, W_3 + n\gamma_3 \frac{d\mathrm{E}\, W_3}{dn} + N_2\gamma_2 \frac{d\mathrm{E}\, W_2}{dn} \\
&+\sum\nolimits_t \alpha(t)\left[\omega_1(s,t) - \omega_3(t) + \frac{d\Omega(t)}{dn}\right] - \mu\left(\frac{d\mathrm{E}\, W_1}{dn} - \frac{d\mathrm{E}\, W_3}{dn}\right) = 0
\end{aligned} \tag{3.19}$$

which implies that the allocation of labor (the number of seasonal workers) must equalize marginal social benefit and marginal social cost of moving one more rural resident to work in the urban sector.

If we assume *ex ante* utility function is in log form (the degree of relative risk aversion is 1) with $W_i = \ln\left(v_i(t)\right)$, the optimization problem can be solved as:

$$\mu = \frac{(N_1 - n)\, n\left[\gamma_3\omega_1(t) - \gamma_1\omega_3(t)\right]}{n\omega_3(t) + (N_1 - n)\,\omega_1(t)}, \text{ for all } t \tag{3.20}$$

$$\frac{\alpha(t)}{\pi(t)} = \frac{\gamma_1(N_1 - n) + \gamma_3 n}{n\omega_3(t) + (N_1 - n)\,\omega_1(t)} = \frac{\gamma_1(N_1 - n) + \gamma_2 N_2 + \gamma_3 n}{\Omega(t)}, \text{ for all } t \tag{3.21}$$

$$\omega_2(t) = \rho_2\Omega(t) = \frac{\gamma_2}{\gamma_1(N_1 - n) + \gamma_2 N_2 + \gamma_3 n}\Omega(t), \text{ for all } t \tag{3.22}$$

Equation (3.22) implies that an urban resident is allocated with the amount of goods worth a fixed proportion of social aggregate economic value of goods, independent of the state of the world. As for rural producers and seasonal workers, it is determined by equation groups:

$$\frac{\gamma_3\omega_1(t) - \gamma_1\omega_3(t)}{n\omega_3(t) + (N_1 - n)\,\omega_1(t)} = \frac{\gamma_3\omega_1(t') - \gamma_1\omega_3(t')}{n\omega_3(t') + (N_1 - n)\,\omega_1(t')}, \text{ for } t \neq t' \tag{3.23}$$

$$(N_1 - n)\,\omega_1(t) + n\omega_3(t) = (1 - N_2\rho_2)\,\Omega(t), \text{ for all } t \tag{3.24}$$

$$\sum\nolimits_t \pi(t)\ln A_1(t)\,\omega_1(t) = \sum\nolimits_t \pi(t)\ln A_3(t)\,\omega_3(t) \tag{3.25}$$

From (3.23) it can be deduced that the redistribution must not be conditional on collective states. One feasible allocation is to let the rural producer and the seasonal worker consume goods worth fixed proportions of social aggregate economic value across all collective states, denoted by ρ_1 and ρ_3, respectively:

$$\rho_1 = \frac{\mathrm{e}^{A_3}}{\left[\left(N_1 - n\right)\mathrm{e}^{A_3} + n\mathrm{e}^{A_1}\right]}\left(1 - N_2\rho_2\right), \rho_3 = \frac{\mathrm{e}^{A_1}}{\left[\left(N_1 - n\right)\mathrm{e}^{A_3} + n\mathrm{e}^{A_1}\right]}\left(1 - N_2\rho_2\right), \quad (3.26)$$

in which e^z denotes the Natural logarithm with $A_i = \sum_t \pi(t) \ln A_i(t)$.

Given the specification, the equilibrium number of seasonal workers is determined by:

$$\begin{aligned}&\left(\gamma_3 - \gamma_1\right)\mathrm{E}\,W_1 + \sum_t \pi(t)\left[\left(N_1 - n\right)\gamma_1 \frac{1}{A_1(t)}\frac{dA_1(t)}{dn} + \left(N_2\gamma_2 + n\gamma_3\right)\frac{1}{A_3(t)}\frac{dA_3(t)}{dn}\right] \\ &+\sum_t \alpha(t)\left[\omega_1(t) - \omega_3(t) + \frac{d\Omega(t)}{dn}\right] - \mu\sum_t \pi(t)\left(\frac{1}{A_1(t)}\frac{dA_1(t)}{dn} - \frac{1}{A_3(t)}\frac{dA_3(t)}{dn}\right) = 0\end{aligned} \quad (3.27)$$

with

$$\begin{aligned}\frac{1}{A_1(t)}\frac{dA_1(t)}{dn} &= -\frac{\epsilon^2}{\epsilon+1}\frac{N_1\left(w(t) - c\right) + N_2 w(t)}{\left(N_1 - n\right)\left[\epsilon B(t) - \delta_x\left(N_1 - n\right)\mathrm{EX}(t)\right]} \\ \frac{1}{A_{2,3}(t)}\frac{dA_{2,3}(t)}{dn} &= -\frac{\epsilon^2}{\epsilon+1}\frac{N_1\left(w(t) - c\right) + N_2 w(t)}{\left(N_1 - n\right)\epsilon B(t)}\end{aligned}, \text{ and}$$

$$\frac{d\Omega(t)}{dn} = (1+\epsilon)\left(w(t) - c\right) + \delta_x \mathrm{EX}(t)$$

Here we have a special case when $c = 0$ and $\delta_x = \delta_y = 0$, it holds that $A_1(t) = A_{2,3}(t)$ and $\rho_1 = \rho_3$. If the central planner is treating the rural producer and the seasonal worker equally with $\gamma_1 = \gamma_3$ (it can be found later in this chapter that when $A_1(t) = A_{2,3}(t)$, this equality necessarily holds), the equilibrium number of seasonal workers is $\epsilon / (1+\epsilon)$, which equals to the power of the rural good in the utility function.

3.5 MARKET ALLOCATION OF DISASTER RISK

In this section, Malinvaud-Arrow (M.A.) insurance system is employed to insure the disaster risk. When there is M.A. insurance system in the world of this model, the sequence of events change to: a) decision-making on migration; b) underwriting of M.A. insurance policy; c) production; d) determination of the state of the world; e) exercise of insurance contract, trade, and consume. For the convenience of discussion, individuals are allowed to pay premium of M.A. insurance *ex post*. Individuals' optimization problem is:

$$\max_{m(s,t),a_i(t)} \mathrm{E}\,W_i = \sum \pi(\cdot) W_i\left(v_i\left(\omega_i(\cdot)\right)\right), \text{ for } i=1,2,3$$

subject to:

$$\begin{aligned} &\omega_1(s,t) = e_1(s,t) + \left[m(s,t) - \sum_{s'} \pi(s' \mid t) m(s',t)\right] \\ &\qquad + \left[a_i(t) - \sum_{t'} r(t') a_i(t')\right] \\ &\omega_{2,3}(t) = e_{2,3}(t) + \left[a_{2,3}(t) - \sum_{t'} r(t') a_{2,3}(t')\right] \\ &e_1(s,t) = p(t) X(s), e_2(t) = w(t), e_3(t) = w(t) - c \end{aligned} \quad \text{, for all } s, t. \tag{3.28}$$

The second item on the *r.h.s.* (right hand side) of the budget constraint for the rural producer denotes the mutual insurance contract. $m(s,t)$ is the mutual insurance coverage against a joint state of (s,t). The premium rate for the mutual insurance contract against a joint state (s,t) is exactly the conditional probability of s on t (Yokomatsu and Kobayashi, 2000). Urban workers do not use the mutual insurance system as they have no difference in their individual states, or in other words all urban workers have only one and the same individual state. The last items on the *r.h.s.* denote the transaction of Arrow security with $a_i(t)$ denoting the amount of Arrow security held by individual of type *i* and $r(t)$ denoting the market-clearing price of per unit of Arrow security against a collective state *t*. Suppose the Lagrangain multiplier for rural producers is $\lambda_1(s,t)$. First-order condition can be derived as:

$$\begin{aligned} \pi(s,t)\frac{dW_1(\cdot)}{d\omega_1(s,t)} &= \lambda_1(s,t) \\ \pi(s \mid t)\sum_s \lambda_1(s,t) &= \lambda_1(s,t) \\ r(t)\sum_s \lambda_1(s,t) &= \sum_{s,t} \lambda_1(s,t) \end{aligned} \quad \text{, for all } s, t \tag{3.29}$$

If we define $\lambda_1(t) = \sum_s \lambda_1(s,t)$ and $\lambda_1 = \sum_{s,t} \lambda_1(s,t)$, the first-order conditions for the rural producer yield

$$\pi(t)\frac{dW_1(\cdot)}{d\omega_1(s,t)} = r(t)\lambda_1 \text{, for all } s, t \tag{3.30}$$

The *r.h.s.* of (3.30) is only dependent on the collective state of the world. Therefore, the state-contingent wealth of the rural producer is actually independent on individual state, which implies that rural producers will choose full mutual insurance coverage.

$$m_1(s,t) = p(t)\left[X(0) - X(s)\right] \text{, for all } s, t, \tag{3.31}$$

in which we use $X(0)$ to denote the individual damage-free state. After fulfilling the mutual insurance contract, rural producers will have the same state-contingent wealth equal to the expected labor income across all individual states

$$\begin{aligned} &e_1(s,t) + \left[\sum_{s'} \pi(s' \mid t) m(s',t) - m(s,t)\right] \\ &= \mathrm{E}\left[p(t) X(s)\right] = p(t)\sum_s \pi(s \mid t) X(s) = p(t)\mathrm{EX}(t) \end{aligned} \quad \text{, for all } s, t \tag{3.32}$$

Then budget constraints can be generalized to:

$$\begin{aligned}\lambda(t): \omega_i(t) &= e_i(t) + \left[a_i(t) - \sum\nolimits_{t'} r(t') a_i(t')\right] \\ : e_1(t) &= p(t)\mathrm{EX}(t), e_2(t) = w(t), e_3(t) = w(t) - c\end{aligned}\text{, for all } t \tag{3.33}$$

The first-order conditions for budget constraints in (3.33) are:

$$\pi(t)\frac{dW_i(\cdot)}{d\omega_i(t)} = \lambda_i(t), \lambda_i = \sum\nolimits_t \lambda_i(t), r(t)\lambda_i = \lambda_i(t)\text{, for all } t \tag{3.34}$$

Again we assume the *ex ante* utility function is CRRA of degree 1 ($\theta = 1$) and solve step forward:

$$\omega_i(t) = \frac{\pi(t)}{\lambda_i r(t)} \Rightarrow e_i(t) + \left[a_i(t) - \sum\nolimits_{t'} r(t') a_i(t')\right] = \frac{\pi(t)}{\lambda_i r(t)} \tag{3.35}$$

As we know from (3.34) that $\sum_t r(t) = 1$, it follows that

$$\lambda_i = \frac{1}{\sum_t r(t) e_i(t)} \tag{3.36}$$

Following relationship can be derived with (3.34), (3.35) and (3.36):

$$\frac{\pi(t)}{r(t)}\left[(N_1 - n)\sum\nolimits_{t'} r(t') e_1(t') + N_2 \sum\nolimits_{t'} r(t') e_2(t') + n\sum\nolimits_{t'} r(t') e_3(t')\right] = \Omega(t),$$

which is equivalent to:

$$\frac{\pi(t)}{\pi(t')} = \frac{r(t)\Omega(t)}{r(t')\Omega(t')} \tag{3.37}$$

Then the equilibrium with M.A. insurance system is:

$$r(t) = \frac{\pi(t)}{\Omega(t)} \Big/ \sum\nolimits_{t'} \frac{\pi(t')}{\Omega(t')}\text{, for all } t \tag{3.38}$$

$$\lambda_i = \frac{\sum_t \pi(t)/\Omega(t)}{\sum_t \pi(t) e_i(t)/\Omega(t)}, \tag{3.39}$$

$$\omega_i(t) = \frac{\pi(t)}{\lambda_i r(t)} = \Omega(t)\sum\nolimits_{t'} \pi(t')\frac{e_i(t')}{\Omega(t')}\text{, for all } t \tag{3.40}$$

The *r.h.s.* of (3.40) is a constant times the state-contingent social aggregate economic value of goods. It is an interesting feature of the M.A. insurance to let each type of individuals to consume exactly the amount of goods worth a fixed proportion of social aggregate economic value irrespective of the state the world. A special case is that if the state-contingent income in terms of urban goods is proportional on social aggregate wealth in terms of urban goods across all collective states, $e_i(t) = k\Omega(t)$, we shall have:

$$\omega_i(t) = \Omega(t)\sum_{t'}\pi(t')k = k\Omega(t) = e_i(t)$$

It means that individuals whose state-contingent income is proportionate to social aggregate wealth will not purchase any Arrow security. In our model when goods tradability is assumed to be perfect, namely $\delta_x = \delta_y = 0$, rural producers will not use the Arrow security market and $e_1(t) = \frac{\epsilon}{\epsilon+1}\frac{\Omega(t)}{N_1 - n}$. This comes from the assumption of C-D utility which consequently preserves the value of rural goods in the society. So after fulfilling mutual insurance contract, individual wealth of rural producers is not contingent on collective states any more. Naturally, there is no need for them to insure it.

3.6 EFFICIENCY ISSUES AND GOVERNMENT INTERVENTION

3.6.1 Efficiency of decentralized approaches

The benchmark optimum is described by:

$$n_0 = \arg\left\{n \in [0, N_1]; \sum_{s,t}\pi(s,t)W_1\left(v_1\left(p(t)X(s)\right)\right) = \sum_t \pi(t)W_3\left(v_1\left(w(t)-c\right)\right)\right\} \tag{3.41}$$

As for the social optimum,

$$n_s = \arg\left\{\begin{array}{l} n \in [0, N_1]; \\ \sum_t \pi(t)(\gamma_3 - \gamma_1)W_1(t) - \sum_t \frac{\pi(t)\epsilon^2}{\epsilon+1}\left[\begin{array}{l} \gamma_1 \frac{N_1[w(t)-c] + N_2 w(t)}{\epsilon B(t) - \delta_x(N_1 - n)\mathrm{EX}(t)} \\ +(n\gamma_3 + N_2\gamma_2)\frac{N_1[w(t)-c]+N_2 w(t)}{(N_1 - n)\epsilon B(t)} \end{array}\right] \\ +\sum_t \pi(t)\left[\gamma_1(N_1 - n) + \gamma_2 N_2 + \gamma_3 n\right]\left[\rho_1 - \rho_3 + \frac{(1+\epsilon)(w(t)-c) + \delta_x \mathrm{EX}(t)}{\Omega(t)}\right] \\ +\frac{(N_1 - n)n[\gamma_3\rho_1 - \gamma_1\rho_3]}{n\rho_3 + (N_1 - n)\rho_1}\sum_t \frac{\pi(t)\epsilon^2}{\epsilon+1}\left[\begin{array}{l} \frac{N_1(w(t)-c)+N_2 w(t)}{(N_1-n)\epsilon B(t)} \\ -\frac{N_1(w(t)-c)+N_2 w(t)}{(N_1 - n)\left[\epsilon B(t) - \delta_x(N_1 - n)\mathrm{EX}(t)\right]} \end{array}\right] = 0 \end{array}\right\} \tag{3.42}$$

The M.A. insurance market solution:

$$n_m = \arg\left\{n \in [0, N_1]; \sum_t \pi(t)\ln A_1(t)\sum_{t'}\pi(t')\frac{e_1(t')}{\Omega(t')} = \sum_t \pi(t)\ln A_3(t)\sum_{t'}\pi(t')\frac{e_3(t')}{\Omega(t')}\right\} \tag{3.43}$$

We are interested in how factor mobility and goods tradability affect the efficiency of allocating resources as well as disaster risk in this small world. In order to make the social optimum and market solution comparable, we apply the necessary condition for equivalency of social optimum and market solution (Yokomatsu and Kobayashi, 2000):

$$\gamma_i \lambda_i = 1 \tag{3.44}$$

As equations are not tractable analytically, numerical examples are employed. Suppose there are two collective states of nature, a Lucky state in which disasters do not happen while an Unlucky state in which disasters happen and destroys a part of production. They are denoted by collective state 0 and 1, denoting the arrival of natural disasters, respectively.

$$t \in \{0,1\},\ \ \pi(t=0) = 0.5,\ \ \pi(t=1) = 0.5.$$

It is assumed that there are two individual states of nature, $s \in \{0,1\}$, too. The conditional probabilities that bridge each collective state and individual state are:

$$\pi(0 \mid 0) = 1,\ \ \pi(1 \mid 0) = 0,\ \ \pi(0 \mid 1) = 1/3,\ \ \pi(1 \mid 1) = 2/3.$$

There are $N_1 = 30000$ residing in the rural area, $N_2 = 10000$ residing in the urban area. When the yield of one piece of land is not destroyed by natural disaster, the producer gets $X(0) = 20$. If unfortunately the yield is destroyed, the producer only gets $X(1) = 5$. The wage paid to workers in the urban sector in two collective states are $w(0) = 30$ and $w(1) = 20$, respectively. The elasticity of substitution is assumed to be $\epsilon = 1$. Numerical examples use $\delta_x = \delta_y = \delta$ and c as parameters. The results are shown in Fig. 3-4 and Fig. 3-5.

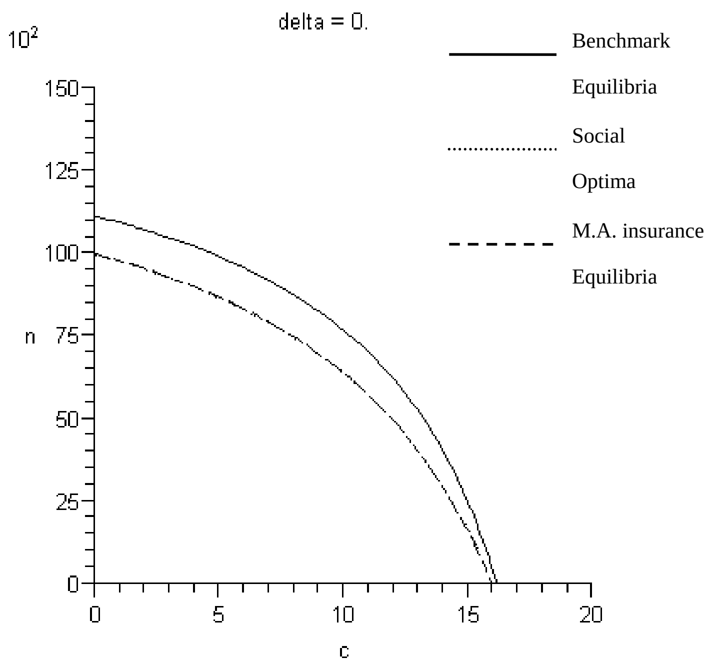


Fig. 3-4 Number of seasonal workers at Equilibria (delta=0)

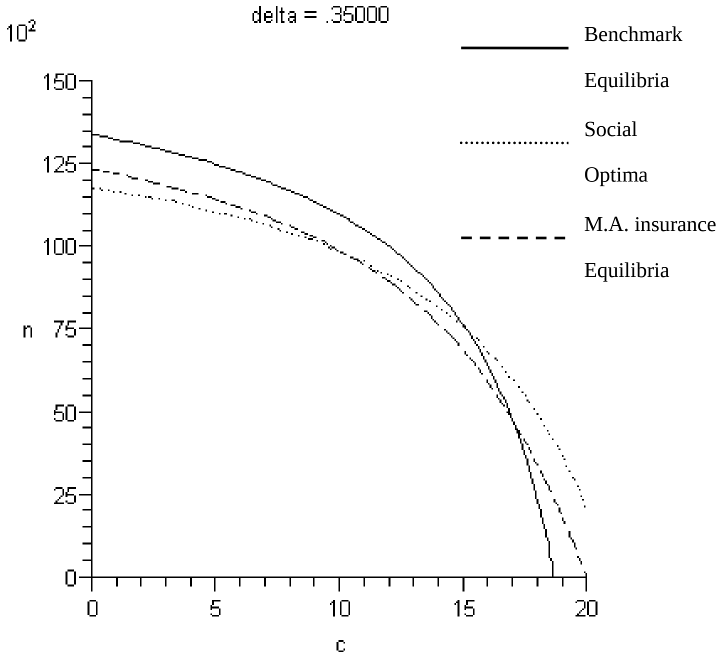


Fig. 3-5 Number of seasonal workers at Equilibria (delta=0.35)

When goods tradability is perfect ($\delta_x = \delta_y = 0$), labor mobility actually has no impact on the efficiency of insurance market solutions. Equilibria achieved by M.A. insurance market are equivalent to social optima. This is because the C-D *ex post* utility function preserves the value of rural goods and consequently collective risk only exists in the urban sector. Meanwhile, social optimal number of seasonal workers is no larger than that in the benchmark case. In this sense, the number of seasonal workers should be controlled.

When goods tradability is not perfect with positive transaction costs, seasonal moves should be either discouraged or encouraged. When the costs for working in the urban sector is low, seasonal moves should be controlled, the same as the previous case. In case the transaction costs for seasonal move are high, however, social optimum requires more labors allocated to the urban sector than the benchmark case. Meanwhile, the social optima and M.A. insurance Equilibria diverge. We see $n_m > n_s$ when c is relatively small. This is because actually only the rural producers are paying the transaction costs for shipping goods, as mentioned before. n_m, however, drops faster than n_s. If the transaction costs for moving to the urban area is high enough to let the negative impact on seasonal workers larger than the impact of goods tradability on rural producers, we have $n_m < n_s$ and social optimum encourages more rural residents to work in the urban sector. This divergence between social optima and M.A. insurance Equilibria implies that externality is induced due to the existence of imperfect goods tradability, the transaction costs in transporting goods between rural and urban areas in this model. Therefore, government intervention is necessary to modify the M.A. insurance equilibrium.

3.6.2 Government intervention strategies

In order to diminish the efficiency loss induced by the externality, the intervention is expected to change rural residents' decision-making on seasonal moves so that there is exactly the social optimal number of seasonal workers. We introduce two types of government intervention here to achieve the desirable efficient allocation of labor force between sectors.

Lump-sum transfer

Suppose that the government uses lump-sum transfers of wealth in terms of wage among three types of individuals, budget constraints of three types of individuals change to:

$$\omega_i(t) = e_i(t) + \left[a_i(t) - \sum\nolimits_{t'} r(t') a_i(t')\right] + \tau_i, \text{ for all } t, \text{ and } i=1, 2, 3, \qquad (3.45)$$

with $e_1(t) = p(t)\,\mathrm{EX}(t), e_2(t) = w(t), e_3(t) = w(t) - c$. In (3.45) τ_i is the lump-sum transfer of wealth which is assumed to be finished *ex ante*. It represents tax against the seasonal move when it is negative while subsidy when it is positive. The sequence of events changes to: 1) the government announce such kind of lump-sum transfer program in order to en/discourage seasonal moves; 2) rural residents adjust their decision-making on accordingly, taking tax/subsidy as exogenous parameter; and 3) by observing rural residents' behavior, the government choose its intervention strategy, namely the lump-sum tax/subsidy vector, to adjust the number of seasonal worker to social optimal one.

An individual's optimization problem implies that:

$$\omega_i(t) = \Omega(t) \sum\nolimits_{t'} \pi(t') \frac{e_i(t') + \tau_i}{\Omega(t')} = \Omega(t)\,\rho_i^L, \text{ for all } t \qquad (3.46)$$

which is straightforward by substituting $e_i(t) + \tau_i$ for $e_i(t)$ in (3.40). Again we observed that individuals' state-contingent wealth is a fixed proportion of social aggregate wealth even with government intervention, detonated by ρ_i^L. Then the redistributive vector achieves efficiency if the number of seasonal workers determined by the market approach with government intervention,

$$n_m^L = \left\{ n \in [0, N_1]; \sum\nolimits_t \pi(t) W\left(v_1\left(\rho_1^L \Omega(t)\right)\right) = \sum\nolimits_t \pi(t) W\left(v_3\left(\rho_3^L \Omega(t)\right)\right) \right\},$$

equals n_s, the one determined in (3.42). If ρ_i^{L*} meets the requirement, the intervention plan can be denoted as:

$$\tau_i = \left[\rho_i^{L*} - \sum\nolimits_t \frac{\pi(t) e_i(t)}{\Omega(t)}\right] \Big/ \sum\nolimits_t \frac{\pi(t)}{\Omega(t)} \qquad (3.47)$$

Note that we can have a number of intervention strategies that guarantees curves $\mathrm{E}\,W_1$ and $\mathrm{E}\,W_3$ intersect at the social optimal point n_s, which only determines the horizontal position of this intersection. The government can let both curves intersect at a very high position in Fig. 3-2 by allocating rural and seasonal workers a lot of goods but urban residents only a few to consume, or vice versa. This situation occurs because of urban residents in this model have nothing to do with the optimal allocation of labor and the government can allocate them any arbitrary amount of goods without affecting the efficiency of labor and risk allocation. If the central planner wants to maximize social welfare simultaneously then the intervention should let $\rho_2^{L*} = \rho_2$ as determined in (3.22). Alternatively, if the government wants to minimize the side effect of intervention, then $\tau_2 = 0$.

It is straightforward that the budget constraint of the government holds, $(N_1 - n)\tau_1 + N_2\tau_2 + n\tau_3 = 0$, as budget constraints of all other groups of individuals hold.

Subsidy system on insurance premium

As mentioned in the introduction part, government-sponsored subsidy system is widely adopted in crop insurance program in many countries. One of the purposes of adopting such a policy is to create incentives for famers to stay in agriculture sector and maintain their production output level. Therefore if designed appropriately it can also achieve the goal of changing rural residents' decision-making on seasonal move. The intervention strategy is as follows: the government imposes a tax χ_i on and offer mandatory premium rates $R_i(t)$ for individual of type *i*. Individuals will then choose personal optimal amount of insurance coverage, $a_i(t)$, taking χ_i and $R_i(t)$ as exogenous parameter. After observing individuals' optimal behavior, the government chooses combinations of χ_i and $R_i(t)$ to change the number of seasonal workers exactly equal to the one in the social optimum case; then finally the subsidy system consists of subsidy on premium rate $R_i(t) - r(t)$ and lump-sum tax χ_i is determined.

Let us look at the optimization problem of individuals. The budget constraints are:

$$\begin{gathered}\zeta_i(t) : \omega_i(t) = e_i(t) - \chi_i + \left[a_i(t) - \sum\nolimits_{t'} R_i(t') a_i(t)\right] \\ e_1(t) = p(t)\,\mathrm{EX}(t), e_2(t) = w(t), e_3(t) = w(t) - c\end{gathered}\text{, for all } t \tag{3.48}$$

First-order conditions can be derived as:

$$\begin{gathered}\pi(t)\frac{1}{\omega_i(t)} - \zeta_i(t) = 0 \\ \zeta_i(t) - R_i(t)\sum\nolimits_{t'} \zeta_i(t') = 0\end{gathered}\text{, for all } t \tag{3.49}$$

and optimal choices can be derived:

$$\begin{aligned}\omega_i(t) &= \frac{\pi(t)}{R_i(t)}\sum\nolimits_{t'} R_i(t')\left[e_i(t') - \chi_i\right] \\ a_i(t) &= \omega_i(t) - \left[e_i(t) - \chi_i\right] + \sum\nolimits_{t'} R_i(t') a_i^*(t'), \text{ for all } t \\ R_i(t) &= \frac{\pi(t)}{\omega_i(t)} \Big/ \sum\nolimits_{t'} \frac{\pi(t')}{\omega_i(t')}\end{aligned} \tag{3.50}$$

Let $\omega_i(t) = \rho_i^P(t)\Omega(t)$. The subsidy system on insurance premium is successful if the number of seasonal workers determined by this intervened market equilibrium equals n_s . If the redistribution meets conditions mentioned above is $\rho_i^{P*}(t)$ for all *i* and *t*, the intervention strategy is determined by:

$$R_i(t) = \frac{\dfrac{\pi(t)}{\rho_i^*(t)\Omega(t)}}{\sum_{t'}\dfrac{\pi(t')}{\rho_i^*(t')\Omega(t')}}, \chi_i = \frac{\sum_t \dfrac{\pi(t)e_i(t)}{\rho_i^*(t)\Omega(t)} - 1}{\sum_t \dfrac{\pi(t)}{\rho_i^*(t)\Omega(t)}}, \text{ for all } t \tag{3.51}$$

Again there are a number of intervention strategies, as discussed in the previous section. Moreover, the budget constraint of the government is automatically met since all other groups of agents are following their budget constraints.

3.7 SUMMARY

This Chapter has discussed disaster risk diversification and laborer allocation problem between rural and urban sectors. It has focused on the migration behavior (the seasonal move in this model) as a kind of risk management practice of rural laborers. Beyond the classical manner of analysis, his model has also incorporated the concept of collective risk as well as M.A. insurance to show the unique feature of disaster risk. Laborer mobility and goods tradability have been introduced in this model as susceptible issues that might influence the efficiency of resources and risk allocation.

The result of the mode implies that it is inappropriate to argue whether the government should encourage or discourage the seasonal move universally. It can be seen in the model that when goods are assumed to be free to trade, the number of seasonal workers should always be controlled, either with centralized or decentralized instruments. When the transaction costs for shipping goods are taken into account, however, rural residents should be discouraged/encouraged to work in the urban sector to some extent in case that the transaction costs for moving is low/ high.

When goods are perfectly tradable (the transportation cost for moving goods between rural and urban areas in this model is 0), the M.A. insurance market allocates exactly the social optimal number of seasonal workers. Moreover, in this case rural producers use only the mutual insurance system but not the Arrow security market, because when we assume C-D utility function, the value of rural good is preserved and shows no cross-collective-state variability as urban goods are serving as the numeraire, the “money” in this model. When goods tradability is not perfect, however, externality rises and the M.A. insurance system cannot achieve efficient allocation of labor between sectors. The reason can be found in the *ex post* optimal consumption bundle of rural producers. Goods tradability actually only has impact on rural producers’ consumption quantity of urban good, which definitely make rural producers worse off given all other factors remaining the same. In this sense, more rural producers are willing to move to work in the urban than the social optimal one, when the transaction cost for the seasonal move is not large. The situation changes when the transaction cost for the seasonal move goes so high that its negative impact on seasonal worker exceeds the negative impact of goods tradability on rural producers. Then social optimum would encourage more rural residents to conduct the seasonal move than the M.A. insurance equilibrium.

Government intervention is necessary to correct the inefficiency losses induced by externality. Two types of intervention strategy are proposed. The one is lump-sum tax/subsidy on the seasonal move and the other is direct subsidy system on insurance premium which is widely adopted in many countries. The lump-sum transfer, however, is with more solid theoretical basis as the externality is induced by goods tradability but not disaster insurance contracts.

What is happening in most less developed countries follows the benchmark case with some government redistributive policies. The number of seasonal workers is likely to lie between the one in the benchmark equilibrium and social optimum. Specific policies, of course, should be designed according to specific economic environment as this model only provides a very general view on this issue.

There are still several important issues that have not been well framed and explained in this model. The C-D utility function cannot reflect important features of agriculture products. A group of utility functions showing inelastic demand feature of agriculture products and perhaps embodying the subsistence constraint of consumption will help us to catch the essential issues of disaster risk management for agriculture production. This essential structure becomes the job for the models of the subsequent two chapters. Secondly, the subsidy system on insurance premium works for controlling the number of seasonal workers and keep farmers in place. This is, however, not a rigorous justification because rural producers' decision making on optimal production is not taken into account. Moreover, it will be appreciated if premium subsidy is framed as Pigovian tax/subsidy which equalizes the marginal social and individual costs in insuring disaster risk. In that case, the externality must be induced in the insuring process, which is beyond the structure of the current model.

Chapter 4

Agriculture Product, Premium Subsidy, and Inter-sectoral Allocation of Disaster Risk

4.1 OUTLINE OF THIS CHAPTER

Chapter 3 has discussed risk diversification between two sectors, taking into account collective risk, factor mobility, and goods tradability. It has adopted quite general structure with somehow vague definition on goods and preference. Apparently, C-D utility function is not a good choice for the purpose of the model. In this chapter, the model has been refined based on the one in Chapter 3, attaching more focus on goods-specific features so that the discussion is more in the sense of disaster risk diversification between agriculture sector and manufactory sectors.

A model has been developed to provide an alternative explanation of the failure of crop disaster insurance market and verify hypothesis advocating subsidized crop insurance: 1) direct premium subsidy helps the crop insurance market to emerge; 2) subsidized crop insurance encourages rural producers to produce more agriculture products; 3) subsidized crop insurance attract more resources to be engaged in agriculture production; and 4) more abundant agriculture products benefits all consumers in the economy.

The structure of the entire chapter is arranged as below. In section 4.2, key updates in model assumptions from the ones in Chapter 3 are listed. Section 4.3 provides a brief introduction on the utility functions yielding inelastic demand systems with respect to the agriculture product. Given the specific form of utility function, this section also provides the basic discussion on the *ex post* equilibrium of the goods market. In section 4.4 and 4.5, the model discusses *ex ante* investment decision-making of the rural producer, assuming labors are immobile and the population distribution pattern is exogenously determined. Agriculture producers determines how much they want to produce from their land and which level of and crop insurance coverage they want to purchase. In section 4.6, we introduce perfect labor mobility into the results derived in section 4.4 and 4.5 to discuss long run equilibrium and efficiency performance of the subsidized crop disaster insurance. Finally, intuitive policy implications and discussion are provided.

4.2 MODEL ASSUMPTIONS

The model succeeds most of the key assumptions of the previous one in Chapter 3. There are two regions and two sectors, both rural and urban. A population of homogenous individuals is working in this region, either in the rural sector or urban sector. The model is in a static manner and in each period the story is the same. At the beginning of each period, an individual makes decision on which sector he/ she should work in for one period of time. Once decision is made, he/ she will have to work in that sector for the entire period. At the end of each period, individuals get their labor income, either in the form of crop yield or wage, and go to the market to exchange. An individual's state-contingent welfare is then measured by a two-dimensional utility function. Disaster(s) might happen during the process of production and the yield of crops might be damaged. There are insurance available for the rural producers to hedge their risks.

Several updates have been made to match the intension of this model. 1) It is assumed that migration (seasonal move) is for free and bilateral: labors can migrate either from the rural area to the urban area, or the opposite. In other words, the model collapses to a static labor allocation problem. 2) The utility function has switched from C-D from to Quasi-linear form to denote the inelastic demand feature of the rural good so that the model represents goods-specific features. 3) The rural producer is now able to make decision on the optimal output level of production. In this sense we can discuss how their production behavior is affected by (subsidized) crop insurance program. 4) The model collapses to a partial equilibrium where international insurer(s) are introduced, and the central government is assumed to posses external financial resources to conduct direct premium subsidy. 5) A much simplified version of the collective risk concept is applied in this model. There is no state-contingent heterogeneity among rural producers in this model by implicitly assuming there is a frictionless mutual insurance market working for rural producers. This assumption is supported by the result in the model in Chapter 3.

4.3 UTILITY FUNCTIONS FOR MODELING AGRICULTURE GOODS

Utility functions yielding inelastic demand systems

It is the essential change of this model to specify the rural goods to be the agriculture product. There are two major properties of necessary agriculture products for individuals: subsistence constraint and inelastic demand. Subsistence constraint refers to the fact that an individual must consume a certain minimum amount of agriculture products to survive. Inelastic demand means that generally the change in demand for agriculture goods is relatively a slow variable compared to the change in consumers' income or the market price of agriculture goods. On the one hand, according to Engel's law, demand for agriculture product is income elastic as the percentage of income spent on food shall decrease when income increases. One assumption must hold for such a conclusion that consumption is different from expenditure unless all goods have the same price. On the other hand, agriculture product is price inelastic. In other words, the percentage change in the demand is smaller than the percentage change in the market price of the goods, holding the income as fixed.

Then the problem is to provide a utility function yielding a demand system showing inelastic demand with respect to agriculture product. One of the most popular approaches is the famous Stone-Geary form (Neary, 1997; Koskelaa and Puhakka, 2007):

$$u\left(c_1,\dots,c_n\right)=\prod_{i=1}^{n}\left(c_i-\gamma_i\right)^{\beta_i}, \tag{4.1}$$

where c_i is the consumption on *i*th goods with a minimum consumption amount of γ_i, $\gamma_i>0$. β_i are parameters for the *i*th goods and $\sum_i \beta_i=1$. When it comes to dual-economy models with only two types of goods, the utility function is generally put in the Cobb-Douglas form with subsistence constraint on the consumption of agriculture good:

$$u\left(c_a,c_m\right)=A c_m^{\beta}\left(c_a-\gamma\right)^{1-\beta}, 0<\beta<1 \tag{4.2}$$

or its equivalent expression with log functions, with $A=\beta^{-\beta}\left(1-\beta\right)^{\beta-1}$ to simplify notation. This form is widely used in popular macro dual-economy models discussing agriculture and economic development, after some manipulation so that it fits overlapping generations or Ramsey framework (e.g., Matsuyama, 1991; Steger, 2000; Irz and Roe, 2005).

Suppose the income is denoted by e while the relative price of the agriculture good is p, income elasticity and own-price elasticity of demand can be derived as:

$$\begin{aligned}\epsilon_{c_a}^{e}&=\frac{\left(1-\beta\right)ep^{-1}}{\gamma+\left(1-\beta\right)ep^{-1}}\le 1\\ \epsilon_{c_a}^{p}&=\beta\frac{\gamma}{c_a^{*}}-1\ge -1\end{aligned}, \tag{4.3}$$

which is perfect in representing agriculture product. The only weakness of the utility function is its discontinuity due to the existence of minimum consumption level: when the consumption level cannot reach the threshold, the utility function becomes meaningless. In our way of discussion, uncertainty in agriculture production is necessary. In case that in some bad states of nature that the consumer's income is contingently not enough to afford the substance level of consumption, utility then cannot be measured and compared.

A simpler way to derive the inelastic demand system is to use utility functions in the Quasi-linear, according to the systemic and exhaustive discussion on two-good utility functions by Jaegher (2007):

$$u(x,y) = f(x) + y,\ f(x) = \begin{cases} b\dfrac{x^{1-\frac{1}{\alpha}}-1}{1-\dfrac{1}{\alpha}}, 0<\alpha<1 \\ b\ln x, \qquad \alpha=1 \end{cases} \tag{4.4}$$

in which x is the rural good and y is the urban good, and *b* and α are parameters. Parameter *b* represents the degree of necessity of agriculture product to an individual. Following the way in economic textbooks, it can be easily proved that utility functions take the form of (4.4) shows zero income elasticity. In other words, an increase in an individual's income does not make him/ her to consume more rural goods. On the other hand, the own-price elasticity of demand of the rural good is exactly $-\alpha$. It means that when the relative price of the rural good increase by 1 percent, its demand will drop α percent which is slower. In this sense, the demand in the rural good is not very sensitive to the change in its price (for the proof of elasticity, please turn to Appendix I).

If the market relative price for the rural good is p, the first-order condition for optimization is to make the marginal rate of substitution equal to the price. An individual's optimal consumption bundle can be derived as

$$x^* = \min\left[\left(p/b\right)^{-\alpha}, ep^{-1}\right], y^* = \max\left[e - px^*, 0\right] \tag{4.5}$$

It could be the case, however, that an individual does not have enough endowment e to consume at the optimal level when $e < x^* \cdot p$. Then it is called a sort of "starving" problem as the individual cannot meet his/her optimal demand in agriculture goods (e.g., food), and consequently cannot afford any urban goods which is assumed to be far less necessary than the rural good in this model. We see the good feature of the utility function is it is continuous and even when the so-called "starving" problem occurs, welfare states are still measurable.

Through out this chapter, the Quasi-linear utility function is employed instead of the popular Stone-Geary utility function. With the Stone-Geary utility function, a rural producer's *ex post* welfare level may not be a monotonic function with respect to his/her decision variable about the output level he/she wants to produce. Instead, the monotonicity of *ex post* utility function with respect to the ex ante decided output level is much more clear with the Quasi-linear utility function. In this sense, description of the model can be simplified a lot without loss of essential results of the model.

Ex post equilibrium and Edgeworth box analysis

Now let us come back to the *ex post* stage of our familiar model. There are two kinds of product, the agriculture product (A goods) and the urban goods (U goods), produced in the rural sector and urban sector, respectively. There are in total N individuals living and working in this small economy. Without lose of generality, N is normalized to be 1. When it comes to the *ex post* stage of the model, the proportion of population working in the rural sector, $n \in [0,1]$, output of each rural producer, X, labor income of each urban worker, e_2, and aggregate output of the urban sector, $(1-n)e_2$, are known to every economic agent in this small economy.

It is convenient to use Edgeworth box to discuss the *ex post* goods market equilibrium. The first problem for us is how multiple economic agents can be mapped to a two-dimension Edgeworth box. According to the law of shrinking core of an economy, when the market is substantially large and after enough times of duplication, the core of the exchange economy shrinks and finally every consumer belonging to a certain group must be finally end up with some identical consumption bundle. In this sense, two representative economic agents possessing average amount of endowment can represent all agents of the two groups. To apply this law, the number of agents in both groups must be the same, which is not necessarily the case in this model. Instead, we use two representative economic agents, the “rural agent” (RA) and the “urban agent” (UA) to represent the group of all rural producers and the group of all urban workers, respectively. There is no essential difference whether the “average” representative or “aggregate” representative is used, in case that any market approach other than purely competition are ruled out when determining the price of goods.

Now the *ex post* exchange economy is described as below. Firstly, the budget constraint for the rural producer is denoted by:

$$p\left(X - x_1\right) = y_1 \tag{4.6}$$

in which x and y are consumption on A good and U good, respectively. Subscript 1 is used to specify the individual type to be “rural producer”. Similar to Chapter 3, the budget constraint used here actually represents a sort of “subsistence agriculture”. The budget constraint for the urban worker is:

$$e_2 = px_2 + y_2 \tag{4.7}$$

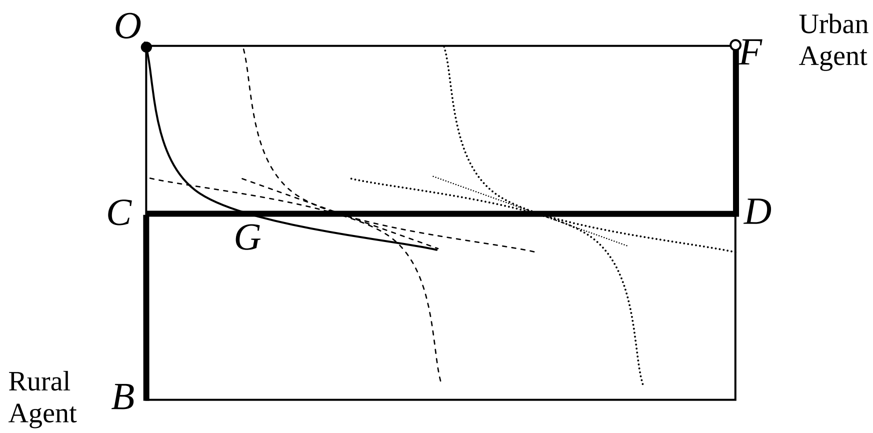


Fig. 4-1 Edgeworth box analysis of the *ex post* equilibrium with Quasi-linear utility function

Then we can draw the Edgeworth box as in Fig. 4-1. The vertical axis of the box denotes the social aggregate A good available to consume while the horizontal axis denotes the social aggregate

U good available to consume. The left-down corner, point *B*, is the origin of indifference curves for the RA while the right-top corner, point *F*, is the one for the UA. Then initially the RA will be located at the left-top point, O , with endowment of $(0, nX)$ (U goods, A goods), and the UA will also be located at the left-top corner *O* with endowment of $((1-n)e_2, 0)$. Since the preference is Quasi-linear in the rural good, increase in utility level just shifts indifferent curves rightward parallelly, or vice versa. The points that indifference curves tangent with each other consist a horizontal line, *CD* in Fig. 4-1. The relative price of the A goods then depends only on social aggregate A goods available for consumption.

The Pareto set of an Edgeworth box are the points where no Pareto improvement can be achieved through exchange, which are assumed to be the efficient distribution results of the exchange economy. The Pareto set of the Edgeworth box in Fig. 4-1 is then the thick segments of *BC*, *CD*, and *DF*. The core of the economy, the segment that is embraced by the indifferent curves that passing through the initial endowment, is *GD* and *DF* with point *F* excluded. Note that with the Quasi-linear utility function, it is not possible to draw an indifference curve of the Urban Agent passing through point *O* as zero consumption in the A goods is equivalent to negative infinite utility. Ending up at point *F* is indifferent with ending up at point *O*. Moving a minor distance from the top edge of the box allows the UA to enjoy utility rise. In this sense, point *F* is not in the core of the exchange economy described in Fig. 4-1.

So where is the *ex post* equilibrium located? According to economic literature, equilibrium of an exchange economy assuming perfect competition must be in the core of such economy and the point(s) where the price offer curves of both agents intersect. In Fig. 4-2 the price offer curves of the RA and the UA are drawn, which are thick segments of *OH-HF* and *BI-IF*, respectively. Note that in the model the a part of the edge of the box is also regarded as parts of the price offer curves, which is of essential importance to our subsequent discussion.

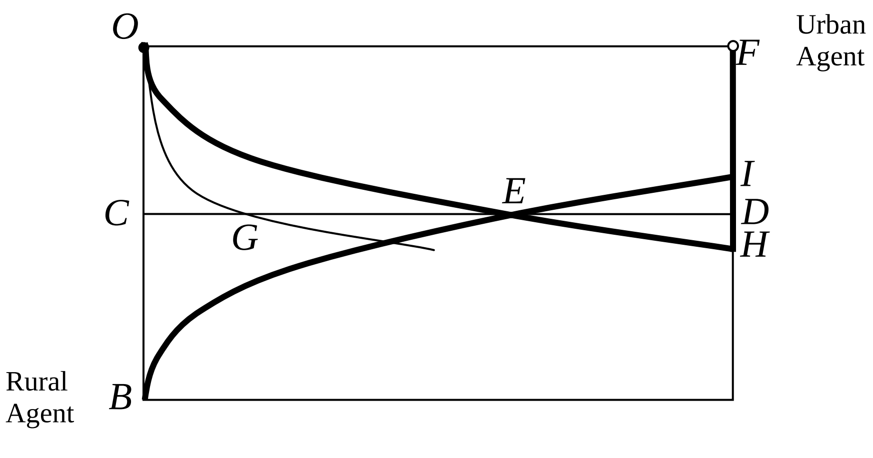


Fig. 4-2 Determination of equilibrium when interior solution can be guaranteed

In the case depicted in Fig. 4-2, the *ex post* equilibrium is then located at point *E*, with final redistribution pattern of:

$$x_{RA} = n^2 X, y_{RA} = b(nX)^{1-\frac{1}{\alpha}}(1-n)$$
$$x_{UA} = n(1-n)X, y_{UA} = (1-n)\left[e_2 - b(nX)^{1-\frac{1}{\alpha}}\right] \tag{4.8}$$

and equilibrium efficient relative price:

$$p = b \cdot (nX)^{-\frac{1}{\alpha}} \tag{4.9}$$

It is interesting to observe that when interior solution is guaranteed, the market will automatically allocate each individual exactly the per capita amount of the A goods. One more thing worth discussion is that there are many overlapping points of price offer curves on the segment *IF* that also meet the requirement of being the equilibrium point. As generally we give priority to interior solutions, those alternatives are ruled out and only point *E* is reserved.

Beyond the most general result, there is another case induced by the impact of inelastic demand that has hardly discussed in popular literatures: the intersection of price offer curves could be located outside of the box, which is not a feasible allocation! Such situation occurs when social aggregate urban goods available is insufficient to allow the equilibrium to reach, $y_{RA} \geq (1-n)e_2$, which could happen either when the output of A good is insufficient or when the income of the urban worker is low. In such a sense, corner solutions must be taken into account.

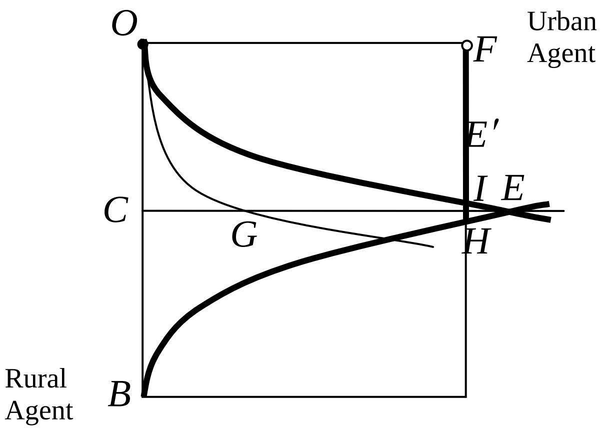


Fig. 4-3 Determination of equilibrium when interior solution cannot be guaranteed

In Fig. 4-3, the equilibrium can only be located at some points on the segment of *IF* except point *F*. The RA will end up with enjoying all the U goods and larger parts of the A goods than the interior equilibrium. The UA will end up with consuming sub-optimal amount of the A goods without any consumption in the U goods. The specific location of the equilibrium, however, cannot be identified without further information. The so-called "starving problem" happens to urban workers, in case that:

$$b(nX)^{1-\frac{1}{\alpha}} > e_2 \tag{4.10}$$

It is equivalent to the case when Stone-Geary utility function is assumed but the social aggregate output of the subsistence goods cannot meet the social aggregate demand for subsistence consumption. But here the trouble is easier to handle, as long as the equilibrium still exists.

The case that the urban worker might suffer from starving while the rural producer is always safe seems a little bit far from what we have learned from the real world. Of course, it comes from the special feature of the utility functions. It could depict the case during extremely hard times, e.g. after mega disaster or a war, urban low income households are more likely to suffer from starving than rural households, as rural households are more accessible to locally produced agriculture products.

4.4 *EX ANTE* DECISION-MAKING: PRODUCTION

The model assumption is relaxed to allow *ex ante* decision-making regarding production for individuals. Suppose labors are still prohibited to choose their job and migrate between the two regions. At the beginning of each period, a rural producer has to decide how much he/she wants to produce for this period, in order to maximize his utility. Due to the focus of the study and also for the ease of description, corner Equilibria are excluded for the rest part of discussion of this chapter. Given the interior equilibrium, *ex post* indirect utility of individuals can be derived as:

$$v_i\left(e_i, p\right) = u_i\left(x_i^*, y_i^*\right) = e_i - \varphi\left(p\right), \text{for } i=1, 2 \tag{4.11}$$

with $e_1 = pX$ and

$$\varphi\left(p\right) = \begin{cases} \dfrac{b^\alpha p^{1-\alpha} - \alpha b}{1-\alpha}, 0 < \alpha < 1 \\ b\left(\ln b^{-1} p + 1\right), \alpha = 1 \end{cases}.$$

The first-order derivative of the indirect utility function with respect to output level is

$$\frac{dv_1}{dX} = \frac{bn^{-\frac{1}{\alpha}}\left[n - \left(1-\alpha\right)\right]}{\alpha} X^{-\frac{1}{\alpha}}, \frac{d^2 v_1}{dX^2} < 0 \tag{4.12}$$

It is amazing to find out here that rural producers may enjoy higher *ex post* welfare if they produce less when the agriculture sector is under-populated such that $n < 1-\alpha$. This is the outcome of applying Quasi-linear utility functions. With Stone-Geary utility functions the result can also be derived except that it depends on the setting of parameters. Moreover, the first-order derivative is likely not to be monotonic when Stone-Geary utility functions are assumed. This is the reason why Quasi-linear utility function is used here instead of Stone-Geary utility functions.

Now we introduce the uncertain nature of agriculture production. The production process in the rural sector is exposed to variability in natural conditions and natural hazards could occur and destroy a part of the production. It is simply assumed that there are two states of nature, the Lucky state in which there is no hazard and yields are not damaged, and the Unlucky state in which natural hazard(s) occur and yields are damaged. In the Lucky state a rural producer gets a yield of $\delta(0)X = X$ while in the Unlucky state this producer gets $\delta(1)X$, with $\delta(1) \le \delta(0) = 1$.

The model assumption on natural disaster risk is largely simplified from the one in Chapter 3. This simplification, however, will not change the essential findings of the model. In Chapter 3 it has been proved that with the frictionless mutual insurance market, all rural producers have identical state-contingent wealth for consumption and they exactly consumes the identical bundle of goods. Moreover, in the case where goods tradability is perfect, rural producers after fulfilling mutual insurance contract becomes risk-equivalent to urban workers and the market for insuring collective risk will not emerge. In this sense, it is no more interesting to assume individual risks and apply the mutual insurance system in this model. By assuming there has already been a perfect mutual insurance system working for rural producers, the focus of discussion can be concentrated to the risk transfer between rural producers and urban consumers. If the collective state is the only concern, the total number of collective states does not matter. Therefore the simplest case of only two collective states of nature has been picked up.

If the *ex ante* utility function takes the form of $W(v_1(\cdot))$, the optimization problem with respect to output level can be described as:

$$\max_X \mathrm{E}\, W_1 = \sum\nolimits_t \pi(t) W\left(v_1\left(e_1(t), p(t)\right)\right)$$

Subject to:

$$e_1(t) = p(t)\delta(t)X - C(X), \text{ for } t=0, 1, \tag{4.13}$$

in which $C(X)$ is the cost function associated to an output level of *X*, with $C'(X) > 0, C''(X) \ge 0$. The first-order condition for optimization requires the optimal output level to hold:

$$\sum\nolimits_t \pi(t)\frac{dW}{dv_1}\frac{\partial v_1}{\partial X} = 0 \tag{4.14}$$

Specifically, when the *ex ante* utility function shows CRRA preference of degree 1, $W(v(\cdot)) = \ln v(\cdot)$, the optimal output level X^* is determined by:

$$\sum\nolimits_t \pi(t)\frac{p(t)\delta(t) - C'\left(X^*\right)}{v_1(t)} = 0 \tag{4.15}$$

When the rural producer is assumed to be risk neutral, the optimal output level is determined by:

$$\mathrm{E}\tilde{p} = C'\left(X^*\right) \tag{4.16}$$

in which $\mathrm{E}\tilde{p} = \sum\nolimits_t \pi(t) p(t)\delta(t)$.

4.5 *EX ANTE* DECISION-MAKING: INSURANCE BEHAVIOR

4.5.1 Viability of the crop disaster insurance market

Agriculture or crop disaster insurance in its true sense refers to the insurance system that in the unlucky state when disaster(s) happen, policyholders get indemnity to compensate for the monetary loss because of the substantial loss in product induced by disasters. If individuals are risk-averse, insurance behavior reduces the difference between individuals' welfare level between the good state and the bad one so that the variance of either state-contingent income or utility is decreased. Consequently, insurance makes policyholders relative worse off in its lucky state by collecting insurance premiums while better off in its unlucky state by paying indemnity. According to this basic principle, we say the rural producer in this model makes use of crop disaster insurance market only when they are worse off in the unlucky state than in the lucky state, with $v_1(0) > v_1(1)$. Derive the necessary condition for this inequality, it is equivalent to the one in (4.12). In other words, if there are relatively a small number of workers producing the rural good, rural producers do not need any insurance against disasters destroying the output of the A goods since they will be actually enjoying higher utility when disasters happen.

Now we assume that the rural sector is over-populated so that $n > 1-\alpha$ and $v_1(0) > v_1(1)$. The next check point is whether crop disaster insurance can be offered domestically from urban workers to rural producers, keeping the model a general equilibrium. Unfortunately the answer is NO.

$$\begin{aligned}
\Delta v_1 &= v_1(0) - v_1(1) = \underbrace{\left[p(0)\delta(0) - p(1)\delta(1)\right]X}_{=\Delta e_1} + \varphi\left(p(0)\right) - \varphi\left(p(1)\right) \\
\Delta v_3 &= v_3(0) - v_3(1) = \varphi\left(p(0)\right) - \varphi\left(p(1)\right) \\
\Delta v_3 - \Delta v_1 &= -\Delta e_1 > 0
\end{aligned} \tag{4.17}$$

since

$$\Delta e_1 = \left[p(0)\delta(0) - p(1)\delta(1)\right]X = b\left(n^2 X\right)^{-1}\left[\delta(0)^{-1} - \delta(1)^{-1}\right] < 0$$

The difference of indirect *ex post* utility of the urban worker is larger than that of the rural producer. Since individuals are assumed to be risk-averse, the urban worker will be more motivated to reduce the variance of *ex post* utility than the rural producer. In this sense, if there is domestic exchange of insurance contract, it must be the case that the rural producer offers the urban worker insurance contract, which is obviously not disaster insurance for agriculture production. Model findings till now are summarized in Proposition 1:

Proposition 1 *In a closed dual-economy where goods markets are purely competitive and clear period by period, producers of inelastically demanded products are relatively advantageous in terms of risks that induce the uncertainty in the output level of those products. The producers enjoy higher* *ex post labor incomes when the output is partly destroyed by the risk. If individuals are assumed to be risk averse, then the consumers of such goods are more in need of insurance against the corresponding risks. Meanwhile, if there is a domestic insurance market to hedge the risk, the producers can only be the supplier of insurance contracts.*

4.5.2 Design of crop disaster insurance

The first implication of proposition 1 is that domestic crop disaster insurance market cannot emerge in the context of the current model. In order to continue our discussion, it is assumed that crop disaster is offered by some international insurance companies and the model collapses to a partial equilibrium. It is necessary to observe how crop disaster insurance contract is offered to producers in real world.

In the United States, crop insurance coverage is offered by Federal Crop Insurance Corporation. There are two major insurance lines offered to producers (Barnett, 2007):

1) Crop yield insurance

Indemnity per acre is calculated by:

$$\textit{indemnity} = \textit{price guarantee} \times \max\,[0, (\textit{trigger yield} - \textit{realized yield})]$$

Where:

price guarantee = (1 – *co-payment*) × *established prices*; the *established price*, based loosely on future price, is set by the federal government prior to planting; and

trigger yield = *coverage level* × *APH yield*. The coverage level is a percentage ranging from 50% to 70%. *APH* is calculated as a rolling 10-year average of yields.

2) Crop revenue insurance

Indemnity per acre is calculated by:

$$\textit{indemnity} = \max\,[0, (\textit{trigger revenue} - \textit{realized revenue})]$$

Where:

trigger revenue = (1 – *co-payment*) × (*APH yield* × *established price*)

realized revenue = *realized yield* × *harvest-time monthly average of closing futures prices on the harvest contract*.

In CAPIP, the insurance contract is basically called "cost insurance". The indemnity per acre covers only the costs for producing one acre of crops. Basically indemnity per acre is calculated by:

$$\text{indeminity}=\text{costs}\times\frac{\max\left[0,\ \left(\text{expected yield - realized yield}\right)\right]}{\text{expected yield}}$$

costs = the costs generated in the process of production, including seeds, fertilizer, pesticide, irrigation, mechanics and so on. Cost on labor is excluded.

The mainstream of contract design of crop insurance implies that the major decision variable for potential policyholders is the area of crop land to insure. In other words, policyholders have to decide and put the number of acres that he wants to insure on the insurance contract. Meanwhile, yield insurance contract in FCIP and the cost insurance contract in CAPIP are quite similar. The only difference is the predefined price guarantee. In CAPIP it is the costs per unit area of crop land while in FCIP it reflects the approximate future price of crops.

In the context of this model, the insurance contract is designed in a very general way following the template of yield insurance and cost insurance. Indemnity per acre can be calculated by:

$$\frac{m}{l} = \sigma \cdot \max\left[0, \bar{\xi} - \frac{\tilde{\delta} X(l)}{l}\right], \tag{4.18}$$

in which m is the total indemnity, l is the acre of insured crops. σ is the indemnity parameter which could be the price guarantee when it refers to yield insurance or costs reimbursement when it represents cost insurance. $\bar{\xi}$ is the predefined trigger yield per acre while $\tilde{\delta} X(l)/l$ denotes the realized yield per acre of the insured crop land, with the random variable $\tilde{\delta} = \{\delta(0), \delta(1)\}$ denoting the arrival of disasters. As heterogeneity of crop land is not taken into account, so it holds that $X(l)/l = X(L)/L$, which means that the average output of the insured crop land is identical to the average of all crop land. This assumption rules out the discussion on adverse selection and moral hazard so that the discussion of the model is more concentrated, but still it can be one extension point for further discussion. In this model revenue insurance is not viable because when disaster happens the income of the rural producer is definitely higher than that in the Lucky state.

4.5.3 Insurance behavior with risk averse preference

Optimal investment behavior

Given the insurance contract offered as above, the insurance behavior of the rural producer can be discussed. Now suppose one or more international insurers come to this country, offering crop disaster insurance contract. The indemnity per acre is calculated according to (4.18). If a rural producer joins this insurance program, he/she will have to pay a premium of νm to cover a monetary loss of m. Note that here ν is the effective premium rate faced by the rural producer which is not necessarily the one that the international insurers offer to them, as government behavior may mask the nominal premium rate by giving a subsidy or imposing a tax.

The rural producer's optimization problem is then to choose the optimal investment strategy to maximize the expected *ex ante* utility:

$$\max_{X,L,l} \mathrm{E}\, W_1 = \sum\nolimits_t \pi(t)\, W\left(v_1(t)\right)$$

subject to:

$$\begin{aligned} e_1(0) &= p(0)\,\delta(0)\,X - C(X) - \nu \cdot m \\ e_1(1) &= p(1)\,\delta(1)\,X - C(X) + (1-\nu)\cdot m \\ m &= \sigma \cdot \left[\delta(0)\,\overline{\xi} - \delta(1)\frac{X}{L}\right]\cdot l \end{aligned} \tag{4.19}$$

There are three decision variables for the rural producer, the aggregate output level X, total area of land to cultivate L, and the area of crop land to insure l. It is assumed that at the beginning of each period, the rural producer makes some loan to finance his/ her costs in planting crops and purchasing insurance coverage. This amount of loan is supposed to repay *ex post*, after labor income of the rural producer is realized. When risk-averse preference is assumed, we allow rural producers to make as much loan as they want.

It is necessary to put some discussion of the difference of trigger yield and realized yield, $\delta(0)\,\overline{\xi} - \delta(1)\,X\,/\,L$. In this model, we use very simple assumption that the rural producer determines only the aggregate output level without specifying production function. For a certain output level *X* there could be a number of combinations of output per unit area of land *X/L* and the total area of land cultivated L. The information of L is transparent to all stakeholders in this model which is directly observable *ex ante*. The information on the average output level *X/L*, however, is generally not observable *ex ante*. In this sense, moral hazards may occur that the rural producer intentionally reduces average output level of the insured crop land after the trigger yield is fixed on the insurance contract. Although the trigger yield is calculated based on by historical data, the information is available *ex post*. In this sense, insurance companies will have to adopt incentive mechanisms to prevent moral hazard from happening. Although it is going to be an interesting point to discuss how this incentive mechanism is designed, it is skipped in this model due to the focus of the study. Then it is assumed that there has been such mechanism working and the rural producer produces exactly at the trigger yield level per unit area of land. This assumption is strong but it keeps our manner of discussion from being diversified, since the discussion on mechanism design will be mainly in the way of thinking of Principle-Agent model.

Therefore, the optimization problem can be re-formulated as:

$$\max_{X,\rho} \mathrm{E}\, W_1 = \sum\nolimits_t \pi(t)\, W\left(v_1(t)\right)$$

subject to:

$$\begin{aligned} \lambda_1(0) &: e_1(0) = p(0)\delta(0)X - C(X) - \nu \cdot m \\ \lambda_1(1) &: e_1(1) = p(1)\delta(1)X - C(X) + (1-\nu) \cdot m \\ \lambda_2 &: m = \sigma \cdot \Delta \cdot X \cdot \rho \\ \lambda_3 &: \rho \le 1 \end{aligned} \tag{4.20}$$

The Greek letter ahead of each budget constraint is its corresponding Lagrangian multiplier. $\rho = l / L$ denotes the coverage level, the proportion of insured land to total crop land cultivated, which should be no larger than 1. $\Delta = \delta(0) - \delta(1)$ is used to denote the ratio of damage claimed by disasters. First-order conditions for optimization can be derived as:

$$\begin{aligned} \pi(t)\frac{\partial W(v_1(t))}{\partial v_1(t)} - \lambda_1(t) = 0, \text{for } t = 0,1 \\ \sum\nolimits_t \lambda_1(t)\left[p(t)\delta(t) - C'(X)\right] + \lambda_2\sigma\Delta\rho = 0 \\ -\lambda_1(0)\nu + \lambda_1(1)(1-\nu) - \lambda_2 = 0 \\ \lambda_2\sigma\Delta X - \lambda_3 = 0 \\ \lambda_3(\rho - 1) = 0, \lambda_3 \ge 0, \rho \le 1 \end{aligned} \tag{4.21}$$

The optimal insurance coverage level may bind and therefore the discussion must be put into two situations.

1) When partial coverage is purchased ($\lambda_3 = 0$, $\rho < 1$)

Therefore, it holds that $\lambda_2 = 0$ and

$$\begin{aligned} \sum\nolimits_t \pi(t)\frac{\partial W(v_1(t))}{\partial v_1(t)}\left[p(t)\delta(t) - C'(X)\right] = 0 \\ -\pi(0)\frac{\partial W(v_1(0))}{\partial v_1(0)}\nu + \pi(t)\frac{\partial W(v_1(1))}{\partial v_1(1)}(1-\nu) = 0 \end{aligned}, \tag{4.22}$$

Then optimal investment behavior (X_{pc}, ρ^*) can be derived, in which the subscript pc is used to denote variables associated to the partial coverage.

2) When full coverage is purchased ($\lambda_3 > 0$, $\rho = 1$)

In this sense, first-order conditions can be updated to:

$$\begin{aligned} \pi(t)\frac{\partial W(v_1(t))}{\partial v_1(t)} = \lambda_1(t), \text{for } t = 0,1 \\ \sum\nolimits_t \lambda_1(t)\left[p(t)\delta(t) - C'(X)\right] = \left[\lambda_1(0)\nu - \lambda_1(1)(1-\nu)\right]\sigma\Delta \end{aligned} \tag{4.23}$$

Then the optimal investment behavior X_{fc} can be derived, where the subscript fc is used to denote variables associated to full coverage insurance.

Comparative statics

1) When partial coverage is purchased

Now we are interested in the investment behavior on the change of effective premium rate. This step is of substantial importance to verify the hypothesis that subsidized premium rate encourages producers to produce higher output of crops. First-order conditions of (4.22) yields

$$(1-\nu)\,p(0)\,\delta(0)+\nu p(1)\,\delta(1)-C'(X)=0\,, \tag{4.24}$$

Let $g\left(X_{pc}(\nu),\nu\right)=(1-\nu)\,p(0)\,\delta(0)+\nu p(1)\,\delta(1)-C'\left(X_{pc}\right)$. It follows that

$$\frac{\partial g\left(X_{pc}(\nu),\nu\right)}{\partial\nu}=p(1)\,\delta(1)-p(0)\,\delta(0)>0$$

According to the envelop theorem, comparative statics imply that

$$\operatorname{sign}\frac{dX_{pc}(\nu)}{d\nu}=\operatorname{sign}\frac{\partial g\left(X_{pc}(\nu),\nu\right)}{\partial\nu}>0\,, \tag{4.25}$$

which means that lower effective premium rate necessarily leads to lower output level of the agriculture product in this model. In other words, when partial coverage is purchased, subsidizing crop insurance premium makes the rural producers to produce less A goods.

2) When full coverage is purchased

Again we are interested in the change of X_{fc} on the change of ν. Define

$$h\left(X_{fc}(\nu),\nu\right)=\sum\nolimits_t \pi(t)\,W\left(v_1(\cdot)\right)$$

Applying Envelope theorem, the relationship follows that:

$$\operatorname{sign}\frac{dX_{fc}(\nu)}{d\nu}=\operatorname{sign}\frac{\partial h^2\left(X_{fc}(\nu),\nu\right)}{\partial X\partial\nu}$$

$$\frac{\partial h\left(X_{fc}(\nu),\nu\right)}{\partial X}=\pi(0)\,\frac{p(0)\,\delta(0)-C'(X)-\nu\sigma\Delta}{v_1(0)}+\pi(1)\,\frac{p(1)\,\delta(1)-C'(X)+(1-\nu)\,\sigma\Delta}{v_1(1)}$$

$$\frac{\partial^2 h\left(X_{fc}(\nu),\nu\right)}{\partial X\partial\nu}=\sigma\Delta\sum\nolimits_t \pi(1)\,\frac{C(X)+\varphi(p(t))-C'(X)\,X}{v_1(t)^2}<0$$

Therefore, it necessarily holds that

$$\frac{dX_{fc}(\nu)}{d\nu}<0 \tag{4.26}$$

When the rural producer is purchasing full coverage, their optimal output level will be increasing with lower premium rate. So finally the investment behavior of the rural producer, using effective premium rate ν as a parameter can be depicted in Fig. 4-4.

There are several critical values of ν :

a) ν_0 is the critical effect premium rate that makes a rural producer to be indifferent of either purchasing insurance coverage or not. When the premium rate goes below ν_0, the rural producer starts to purchase partial coverage and per capita output level starts to decrease.

b) ν_1 is the critical effect premium rate that makes a rural producer to be indifferent of full insurance coverage and partial insurance coverage. At this premium rate, the rural producer produces the lowest output level, which is necessarily smaller than the benchmark output level X_0.

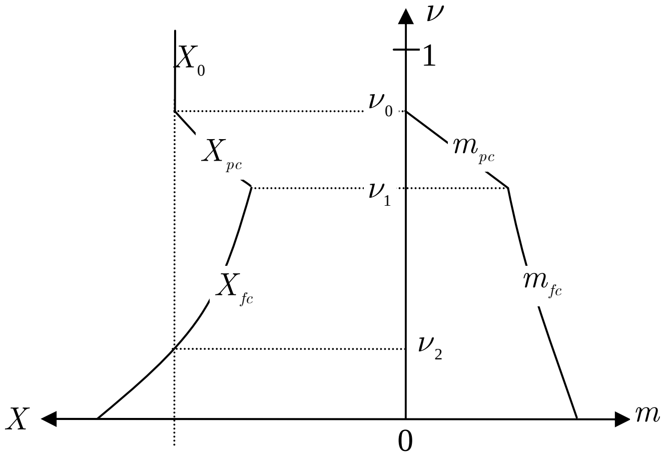


Fig. 4-4 Investment behavior of the rural producer when risk averse is assumed

c) ν_2 is the critical effect premium rate where the output level of a rural producer is identical to the one when no insurance is provided. It is determined by the point where the curves X_0 and X_{fc} intersect. Since X_{fc} must hold the first-order condition of (4.23), the value of ν_2 can be derived by solving:

$$\pi(0)\frac{p(0)\delta(0)-C'(X_0)-\nu\sigma\Delta}{v_1(0)}+\pi(1)\frac{p(1)\delta(1)-C'(X_0)+(1-\nu)\sigma\Delta}{v_1(1)}=0$$

Let

$$\begin{aligned}
A(0) &= p(0)\delta(0)-C'(X_0)\\
A(1) &= p(1)\delta(1)-C'(X_0)+\sigma\Delta\\
B(0) &= p(0)\delta(0)X_0-C(X_0)-\varphi(p(0))\\
B(1) &= p(1)\delta(1)X_0-C(X_0)-\varphi(p(1))+\sigma\Delta X_0
\end{aligned},$$

The solutions of the equation take the form of

$$\nu=\frac{\phi_1\pm\sqrt{\phi_1{}^2-4X_0\phi_2}}{2X_0\sigma\Delta},\text{ with }\begin{aligned}\phi_1 &= \pi(0)\big(B(1)+A(0)X_0\big)+\pi(1)\big(B(0)+A(1)X_0\big)\\ \phi_2 &= \pi(0)A(0)B(1)+\pi(1)A(1)B(0)\end{aligned}$$

Now the sign of ϕ_2 decides how many positive roots we shall have for the equality. As we know, output level X_0 holds the first-order condition for optimization without insurance (4.15). Since all the values of $A(t)$ and $B(t)$ are evaluated at X_0, it holds that:

$$\pi(0)\frac{A(0)}{B(0)}+\pi(1)\frac{A(1)-\sigma\Delta}{B(1)-\sigma\Delta X_0}=0$$

As we know $B(1)>A(1)X_0$, it holds that $\frac{A(1)}{B(1)}>\frac{A(1)-\sigma\Delta}{B(1)-\sigma\Delta X_0}$ and consequently $\phi_2>0$. Therefore there are two intersection points that curve X_{fc} and X_0 intersect each other, between which the smaller one is the only valid solution as it must hold $0<\nu_2<\nu_1$.

d) when $\nu=0$ we have $X_{fc}\mid_{\nu=0}>X_0$. It implies that if the government wants to let the rural producer to produce higher output by subsidizing crop insurance premium, it can obtain the desirable goal only when the effective premium rate falls on the interval of $[0,\nu_2)$.

4.5.4 Insurance behavior with risk neutral preference and liquidity constraint

Optimal investment behavior

The result derived in section 4.3 is very clear but the problem is its tractability. When one tries to derive the explicit analytical solution of optimal investment behavior, troubles will come. Particularly, when factor mobility is taken into account and the population distribution is endogenously determined, which is to be discussed in the next section, it is quite difficult to derive the result under risk aversion assumption. In this sense, the model provides an alternative with risk natural preference under liquidity constraint for the most rigorous result in the last section.

Liquidity constraint here means that when the rural producers make an loan for investment in production and insurance, there is an upper limit for this loan, K. Therefore, the optimization problem can be denoted as:

$$\max_{X,\rho}\mathrm{E}\,V_1=\sum\nolimits_t\pi(t)v_1(t)=\sum\nolimits_t\pi(t)\left[e_1(t)-\varphi(p(t))\right]$$

Subject to:

$$\begin{aligned}
\lambda_1(0)&:e_1(0)=p(0)\delta(0)X-C(X)-\nu m\\
\lambda_1(1)&:e_1(1)=p(1)\delta(1)X-C(X)-\nu m+m\\
\lambda_2&:C(X)+\nu m\le K\\
\lambda_3&:m-\sigma\Delta X\rho=0\\
\lambda_4&:\rho\le 1
\end{aligned}\tag{4.27}$$

The Greek letter ahead of each budget constraint denotes its corresponding Lagrangian Multiplier. The third equation of budget constraint shows the liquidity constraint that the total costs for production plus insurance premium should be no larger than the upper limit of *K*. First-order conditions can be derived as:

$$\begin{aligned} \pi(t)-\lambda_1(t)=0,\ \text{for}\ t=0,1 \\ \lambda_1(0)\left[p(0)\delta(0)-C'(X)\right]+\lambda_1(1)\left[p(1)\delta(1)-C'(X)\right]=\lambda_2 C'(X)-\lambda_3\sigma\Delta\rho \\ -\lambda_1(0)\nu+\lambda_1(1)(1-\nu)-\lambda_2\nu-\lambda_3=0 \\ \lambda_3\sigma\Delta X-\lambda_4=0 \\ \lambda_2\left(C(X)+\nu m-K\right)=0,\lambda_2\geq 0,C(X)+\nu m\leq K \\ \lambda_4(\rho-1)=0,\lambda_4\geq 0,\rho\leq 1 \end{aligned} \tag{4.28}$$

1) When liquidity constraint binds

In this sense, it holds that $C(X)+\nu m=K$ and $\lambda_2>0$. Still we have to differentiate the case of partial coverage insurance and full coverage insurance.

a) When partial coverage is purchased ($\lambda_4=0,\rho<1$)

It also follows that $\lambda_3=0$. If we use X_{pc} and m_{pc} to denote the optimal output level and insurance coverage when partial coverage is purchased, the optimal investment behavior is determined by:

$$\mathrm{E}\tilde{p}=\frac{\pi(1)}{\nu}C'\left(X_{pc}\right),m_{pc}=\frac{K-C\left(X_{pc}\right)}{\nu} \tag{4.29}$$

b) When full coverage is purchased ($\lambda_4>0,\rho=1$)

In this case, optimal investment behavior can be derived by solving the equations below:

$$C\left(X_{fc}\right)+\nu m_{fc}=K,m_{fc}=\sigma\Delta X_{fc} \tag{4.30}$$

2) When the liquidity constraint does not bind

In this sense, it follows that $\lambda_2=0,C(X)+\nu m<K$. The optimization problem is equivalent to:

$$\max_{X,\rho}\mathrm{E}\,V_1=\mathrm{E}\tilde{p}\cdot X-C(X)-\sum\nolimits_t\varphi\left(p(t)\right)+\left[\pi(1)-\nu\right]m$$

Subject to:

$$\begin{aligned} m=\sigma\Delta X\rho \\ \rho\leq 1 \end{aligned} \tag{4.31}$$

Obviously, when $\nu > \pi(1)$, the rural producer will not insure. When $\nu < \pi(1)$, it is optimally to insure as much as possible. In this sense, rural producers must be purchasing full coverage contract with $\rho = 1$. Therefore, optimal investment behavior is described as:

$$\mathrm{E}\tilde{p} = C'\left(X^*\right) - \left[\pi(1) - \nu\right]\sigma\Delta, m^* = \sigma\Delta X^* \tag{4.32}$$

It is worth noting that this investment strategy is SUB-OPTIMAL to (X_{fc}, m_{fc}). Since both investment strategies determined by (4.30) and (4.32) imply full coverage insurance, expected utility is a monotonically increasing function with respect to X. The rural producer then had better to use up all financial resources available to increase X and consequently interior solution on financial resources is ruled out. Result derived in (4.32) shall never be an optimal choice for the rural producer.

Comparative statics

Then it is necessary to discuss the change of optimal investment behavior on the change of effective premium rate so that the effect of policy can be verified.

1) When partial coverage is purchased

First-order conditions in (4.28) yields

$$(1-\nu)\,p(0)\,\delta(0) + \nu p(1)\,\delta(1) - C'(X) = 0 \tag{4.33}$$

Similar to the result in the previous section, inequality (4.25) still holds. Therefore we have:

$$\frac{dX_{pc}(\nu)}{d\nu} > 0, \tag{4.34}$$

which implies that lower premium rate induces rural producers to produce less agriculture product.

2) When full coverage is purchased

We define the discussion function:

$$\begin{aligned} g(X,\nu) = {} & \pi(0)\left[p(0)\,\delta(0)\,X - \varphi\left(p(0)\right) - C(X) - \nu\sigma\Delta X\right] \\ & + \pi(1)\left[p(1)\,\delta(1)\,X - \varphi\left(p(1)\right) - C(X) + (1-\nu)\,\sigma\Delta X\right] \end{aligned}$$

In this case, full coverage will be purchased. Comparative statics can be derived by applying envelope theorem.

$$\frac{\partial g}{\partial X} = \pi(0)\left[p(0)\,\delta(0) - \nu\sigma\Delta\right] + \pi(1)\left[p(1)\,\delta(1) + (1-\nu)\,\sigma\Delta\right] - C'(X)$$

$$\frac{\partial^2 g}{\partial X \partial \nu} = -\sigma\Delta < 0$$

Applying envelop theorem it can be deduced that

$$\frac{dX_{fc}(\nu)}{d\nu} < 0, \tag{4.35}$$

lower premium rate encourages the rural producer to produce higher level of output.

With the discussion above, it is possible to depict the rural producer's investment behavior in a figure. There are two cases to discuss:

1) When the liquidity constraint weakly holds

The phrase "weakly hold" refers to the case that there is an upper limit of making a loan but this amount allows the rural producers to produce their optimal output level when there is no insurance contract available, $K > C(X^0)$. In this sense, the investment behavior is depicted in Fig. 4-5. There are two important reference lines in the figure which are dash lines. The one to the left-most denotes the output level when all financial resources available are used to produce the A goods. The one to the right denotes the output level when there is no crop insurance provided, which refers to the result of (4.16). Again, we have several important values of the effective premium rate:

a) When the effective premium rate is larger than the probability of the event, $\nu > \pi(1)$, a rural producer produces at his/her optimal output level of the no insurance case (determined by (4.16)) and does not purchase any insurance. At $\nu = \nu_0 = \pi(1)$, the rural producer maintains the output level and use all extra accessible financial resources to purchase insurance, which is partial.

b) At effective premium rate ν_1, the rural producer is indifferent of purchasing partial coverage and full coverage. If the premium rate goes lower, they start to purchase full coverage. At this premium rate, the rural producer produces at the lowest output level.

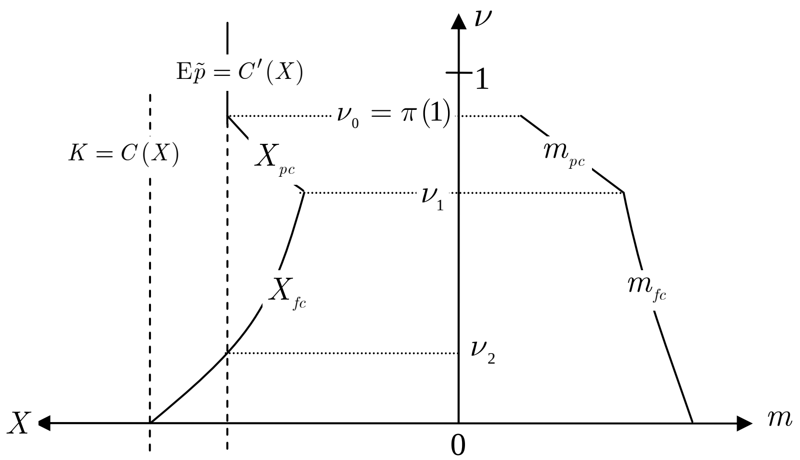


Fig. 4-5 Investment behavior of the risk neutral rural producer with weak budget constraint

c) At some effective premium rate ν_2, the output level will be exactly the same as the one determined by (4.16). Iff the government continues to subsidize insurance premium, the rural producer produces higher level of output.

d) When the crop insurance is provided to rural producers for free ($\nu = 0$), they shall use all financial resources available to produce the A goods and therefore it holds that $K = C(X)$.

2) When the liquidity constraint strongly holds

The phrase "strongly hold" refers to the case that the financial resources available (maximum amount of loan) is (weakly) insufficient to allow rural producers to produce at the optimal output level when there is no insurance provided, $K \le C(X^0)$. This case is depicted in Fig. 4-6.

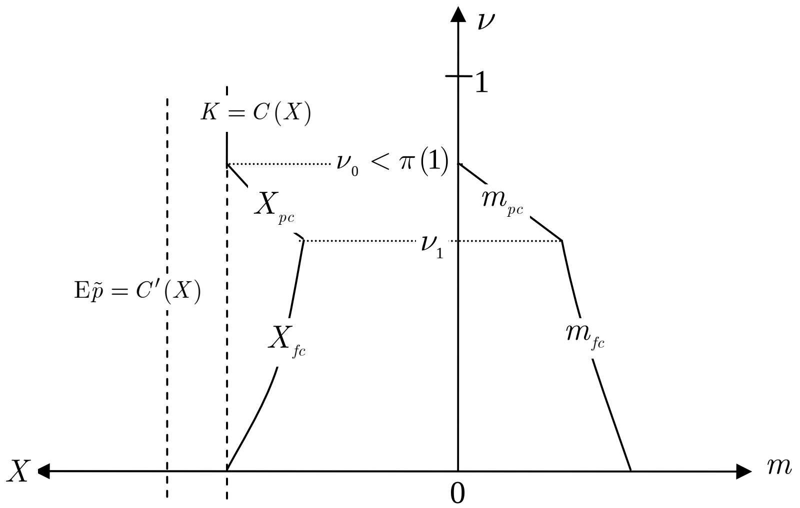


Fig. 4-6 Investment behavior of the risk neutral rural producer with strong budget constraint

Similarly there are several important values of ν as the previous case. When the liquidity constraint is strong, ν_0 changes to be smaller than $\pi(1)$ which means that rural producers cannot afford crop insurance even the price is fair. Meanwhile, $\nu_2 = 0$ in this case and therefore rural producers produces universally no more than the output level when insurance is not provided.

From the result of comparative statics we see that the insurance behavior with risk neutral assumption when liquidity constraint is applied basically coincides with the case with risk averse assumption. Therefore, this setting can be used as an alternative for risk-averse *ex ante* utility functions for the sake of tractability.

To summarize the major findings of this section, we have proposition 2:

Proposition 2 *In the same type of economy as described in proposition 1, if there are some international insurers come to offer disaster insurance against the loss that might be induced by natural disasters, subsidizing the insurance premium does not necessarily encourage producers to increase their output level. If the revenue of per unit output is smaller when disasters do not happen such that* $p(0)\delta(0) < p(1)\delta(1)$ *in this model, producers will be producing lower output level than the case when no disaster insurance is offered. They will be producing at the minimal output level when they are indifferent between full and partial insurance coverage.*

4.6 FACTOR MOBILITY AND LONG-RUN EQUILIBRIUM

In section 4.3 we discussed the investment behavior of the rural producer without touching upon efficiency issues. It is because the population distribution is exogenously determined and it is not possible to compare the expected utilities of the rural producer and the urban worker. In this section, efficiency issues will be discussed by determining stationary population distribution endogenously. The discussion consists of two parts: at first, when there is no crop disaster insurance, the population distribution slowly reaches to its stationary state. Secondly, international insurer(s) come in and provide disaster insurance contract. With crop disaster insurance, the rural producer's investment behavior changes and welfare state of two groups of workers change accordingly. Then migration starts again and finally the population reach to another stationary distribution. Economic efficiency is then compared between the two equilibria.

In this model, it is assumed that labors are perfectly mobile without any transaction costs gendered in the process of migration (seasonal move). Meanwhile, due to the considerable calculation consumption and tractability issue, risk averse assumption is reserved. Moreover, we specify $C(X) = c \cdot X$ to simplify our discussion. Several necessary conditions must hold to make the discussion in this section valid: 1) $n\delta(1)X > b/e_3$ so that corner solution of the *ex post* exchange equilibrium in the goods market does not occur. 2) For any equilibrium population distribution pattern it strongly holds that $n > 1/2$ so that *ex post* indirect utility is an monotonically increase function with respect to output level X.

4.6.1 Stationary population distribution without crop disaster insurance

According to (4.16), the optimal output level of the rural producer is:

$$X_0 = \min\left[\frac{K}{c}, \frac{1}{n_0}\left[\frac{b\mathrm{E}\tilde{\delta}^{-1}}{c}\right]^{\frac{1}{2}}\right], \text{with } \mathrm{E}\tilde{\delta}^{-1} = \sum_t \pi(t)\,\delta(t)^{-1} \tag{4.36}$$

The necessary condition for stationary population distribution is $\mathrm{E}V_1 = \mathrm{E}V_2$,

$$n_0 = \left[\frac{b\mathrm{E}\tilde{\delta}^{-1}}{(e_2 + c \cdot X_0)X_0}\right]^{\frac{1}{2}} \tag{4.37}$$

Then the equilibrium (X_0^*, n_0) can be solved by putting (4.36) and (4.37) together. In order to get a valid solution we have to further assume that the liquidity constraint is strongly hold that $X_0 = K/c$. At this equilibrium, social aggregate welfare is:

$$U_0 = n_0\mathrm{E}V_1 + (1-n_0)\mathrm{E}V_2 = b + (1-n_0)e_2 - \frac{b\mathrm{E}\tilde{\delta}^{-1}}{n_0 X_0^*} \tag{4.38}$$

4.6.2 Long run equilibrium with perfect factor mobility and crop disaster insurance

When international insurer(s) come to provide crop disaster insurance and the effective premium rate is ν, the stationary population distribution pattern is determined by:

$$\frac{b}{n_i^2 X_i^*}\mathrm{E}\tilde{\delta}^{-1}+\frac{\pi(1)}{\nu}\left(K-cX_i^*\right)=e_2+K\text{, for } i=fc, pc \tag{4.39}$$

in which X_i^* is used to denote the optimal output level when factor mobility is taken into account. Subscripts *fc* and *pc* are used to denote full coverage insurance behavior and partial insurance behavior, respectively. Correspondingly the social aggregate welfare is:

$$U_i=b+(1-n_i)e_2-\frac{b}{n_i X_i^*}\mathrm{E}\tilde{\delta}^{-1}+n_i\frac{\pi(1)-\nu}{\nu}\left(K-cX_i^*\right)\text{, for } i=fc, pc$$

Solving for equilibria, we get:

$$n_{pc}=\frac{\left[\frac{b}{\phi}\mathrm{E}\tilde{\delta}^{-1}-\pi(1)c\phi\right]\nu^{\frac{1}{2}}}{(e_2+K)\nu-\pi(1)K}, X_{pc}^*=\frac{\mathrm{E}\tilde{\delta}\left[(e_2+K)\nu-\pi(1)K\right]}{\pi(1)c\left[\mathrm{E}\tilde{\delta}^{-1}-\mathrm{E}\tilde{\delta}\right]} \tag{4.40}$$

$$n_{fc}^2=\frac{b\mathrm{E}\tilde{\delta}^{-1}(c+\nu\sigma\Delta)^2}{K\left[(e_2+K)(c+\nu\sigma\Delta)-\pi(1)\sigma\Delta K\right]}, X_{fc}^*=\frac{K}{c+\nu\sigma\Delta} \tag{4.41}$$

with $\phi=\left[b\mathrm{E}\tilde{\delta}/[\pi(1)c]\right]^{\frac{1}{2}}$, $\mathrm{E}\tilde{\delta}=\sum_t \pi(t)\delta(t)$, and $\mathrm{E}\tilde{\delta}^{-1}=\sum_t \pi(t)\delta(t)^{-1}$.

4.6.3 Comparative statics

By conducting basic comparative statics, it can be found that

$$\frac{dn_{pc}}{d\nu}<0, \frac{dX_{pc}^*}{d\nu}>0, \frac{dX_{fc}^*}{d\nu}<0,$$

The sign of $dn_{fc}/d\nu$ is not certain but it necessarily holds that $n_{fc}>n_0$. The investment behavior when factor mobility is taken into account then can be depicted in Fig. 4-7, which is quite similar to Fig. 4-6. Several critical values of the effective premium rate are labeled with the same denotation as in Fig. 4-6 plus a dash mark.

Moreover, efficiency is described by:

$$\frac{dU_{pc}}{d\nu}>0, U_{pc}\Big|_{\nu=\nu_0'}=U_0 \text{ and } \frac{dU_{fc}}{d\nu}<0, U_{fc}\Big|_{\nu=0}>U_0$$

which is then depicted in Fig. 4-8. For the proof of comparative statics, please kindly refer to Appendix II.

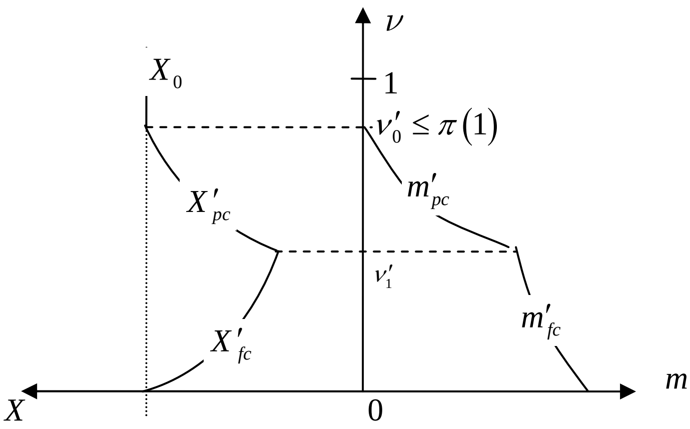


Fig. 4-7 Investment behavior of the risk neutral rural producer under free migration

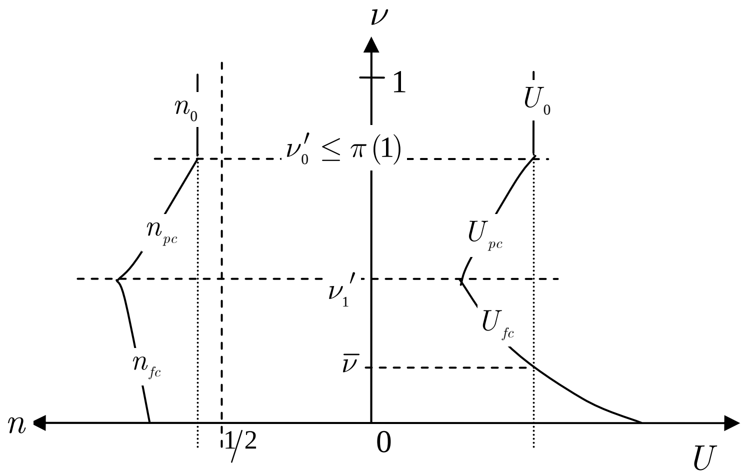


Fig. 4-8 Stationary population distribution and social welfare states

There are several important findings:

a) International insurance brings a sort of "crowd-up" phenomenon in the rural sector that the proportional of population working in the rural sector is necessarily larger than the case when disaster insurance is not provided. Imagine the instance when crop disaster insurance is provided while the population distribution which is assumed to respond in a slow manner has not changed. The rural producer chooses to produce less but their expected utility gets increased because of the insurance. The urban worker, however, suffers from lower expected utility because of higher price for the agriculture product. In this sense, a part of urban workers choose to switch to the rural sector and consequently the proportion of population working in the rural sector increases.

b) Lower effective premium rate does not necessarily lead to higher social aggregate utility. From fig. 4-8 it can be seen that when ν falls on the range of $(\nu_0', \bar{\nu})$ social aggregate utility will be smaller than the one when no crop insurance is provided. In the sense, if the government wants to use either policy or financial instruments to increase social aggregate utility, it should choose either not to let the insurance market emerge or to give substantially subsidy so that the effective premium rate goes below $\bar{\nu}$.

4.7 POLICY IMPLICATIONS

Now we are interested in the thresholds of the government budget that enables the market to emerge and results socially welfare promotion. We simply assume that the inverse supply function of the international insurer is $\nu = \nu(M)$, the up-sloping concave curve in Fig. 4-9. It lies between $\pi(1)$ and 1. Two segments of convex curves are used to denote the demand curve of crop disaster insurance.

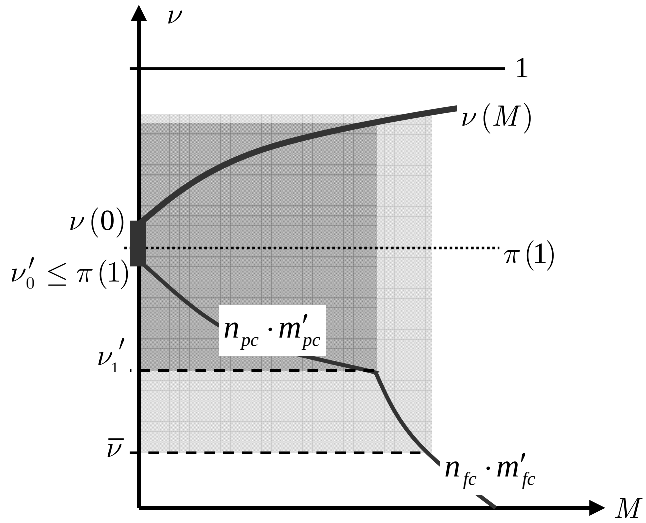


Fig. 4-9 Required financial resources for giving premium subsidy

From previous discussion we know that the effective premium rate that allows the market to emerge is ν_0', which is believed to be weakly smaller than the probability of the event. Correspondingly the demand of insurance will be $m_{pc}(\nu_0')$. In this sense, the government will have to use the budget below to allow the market to emerge:

$$F_0 = \left[\nu\left(n_0(\nu_0')\, m_{pc}(\nu_0')\right) - \nu_0'\right] n_0(\nu_0')\, m_{pc}(\nu_0'), \tag{4.42}$$

which equals to the difference between the premium revenue required by international insurer(s) and actually premium revenue paid by policyholders. In Fig. 4-9, it refers to the length of the black-thick segment on the vertical axis from ν_0' to $\nu(0)$.

In order to allow rural producers to get full coverage, the government has to prepare financial resources up to the area of the dark gray box,

$$F_1 = \left[\nu\left(n_{pc}(\nu_1')\, m_{pc}'(\nu_1')\right) - \nu_1'\right] n_{pc}(\nu_1')\, m_{pc}'(\nu_1') \tag{4.43}$$

If the effective premium rate that makes the social aggregate welfare equivalent to the case without international insurance is $\overline{\nu}$, it must follow that $\overline{\nu} = \arg\left\{\nu; U_{fc}(\nu) = U_0\right\}$. Correspondingly it requests the size of the government budget to be larger than

$$F_2 = \left[\nu\left(n_{fc}\left(\overline{\nu}\right) m'_{fc}\left(\overline{\nu}\right)\right) - \overline{\nu}\right] n_{fc}\left(\overline{\nu}\right) m'_{fc}\left(\overline{\nu}\right) \tag{4.44}$$

to make the insurance contract really beneficial to the local economy. It equals to the area of the light-gray box in Fig. 4-9.

4.8 SUMMARY

The model in this chapter has provided some insights into the popular hypothesis advocating direct subsidy to crop insurance programs. Major findings of the model are summarized as below:

1) Inelastic demand of agriculture goods prevents domestic crop disaster insurance market from emerging. In the small closed dual-economy where the demand to agriculture product is inelastic with respect to both income and demand, rural producers' income will probably be higher when disaster(s) occur and yields are damaged, since the equilibrium price rises faster than the drop in per capita yield of producers. In this sense, urban workers suffer more than rural producers from the impact of disaster, with higher volatility across state-contingent welfare states.

2) The rural producer conditionally needs crop disaster insurance provided by international insurers. The discussion of the model implies that only when the proportion of agriculture producers is high (more inelastic the demand of agriculture product is, higher proportion is required), the rural producer have lower welfare state in the unlucky state when disaster(s) happen. The result directly depends on our assumption of Quasi-linear utility function. The market still does not emerge without price intervention, however, in case that the commercial nominal insurance premium rate is too high.

3) Direct subsidy to crop disaster insurance premium does not necessarily encourage producers to produce more output. A small amount of subsidy only leads to a smaller per capita output level. On the other hand, premium subsidy does induce larger population engaged in agriculture production. This result is very similar to the one derived by Innes (2003) that there is excessive entry into farm production and under-production by operating farmers, although in his model it is induced by *ex post* relief in the absence of *ex ante* government policy.

4) Consequent on 3), social aggregate welfare does not necessarily increase due to direct subsidy to crop disaster insurance premium. The implication for governments is either not to subsidize or subsidize at a very favorable rate in terms of rural producers. The decision largely depends on the financial resources that available for the government. Whether it is cost-effective to invest such amount of fund in subsidizing rural producers beyond the critical point depends on the available investment options for the government, e.g. invest for risk-reduction-measures such as infrastructure for the rural sector. This point is difficult to be touched upon in the current context of the model.

The results of the model, of course, largely depend on the critical assumptions. Firstly, the economy is assumed to be a closed one and consequently no external sources of agriculture products are accessible. Percentage rise of the price of the agriculture product will be larger than percentage drop of aggregate agriculture product output. This structure essentially determines the labor income of the rural producer is higher when the harvest is bad. Secondly, a lot of types of subsistence goods, e.g. cereal products, can be stored for multi-years. Inter-temporal storage of agriculture goods of course can alleviate temporary shortages and prevent state-contingent price from changing dramatically. The static framework of the model rules this possibility out, however.

Moreover, in the current model, it is assumed that there is only one type of rural producers. If there are multiple groups of heterogeneous producers among which the conditional probability vectors bridging collective states and individual states are different, the implication for the efficiency of the economic may be different. In that sense, rural producers whose production is more disaster-damage-resistant, or whose land is more fertile enabling higher expected output level will be the individual group who needs crop insurance the least. Rather, rural producers whose land is located in higher damage-prone regions, or not as fertile as the average level, will suffer the most. Urban consumers in this sense can be either suppliers or demanders of crop insurance, depending on the density function of heterogeneous producers. Light-rate premium subsidy in this sense will discourage those "lucky" producers to produce more from their land, while "unlucky" producers will probably be encouraged to produce more. This may not be the case that policy-makers would like to expect, apparently.

Chapter 5

Alternative Supply, Grain Reserve Policy, and Inter-sectoral Reallocation of Disaster Risk

5.1 OUTLINE OF THIS CHAPTER

The essential finding of the model in Chapter 4 implies that rural producers are relatively advantageous as compared to urban workers in terms of disaster risk. They enjoy higher income level or even higher utility level when disasters happen. The result is rigorously derived by assuming a small, closed, and period-by-period market-clearing economy. It, however, seems to be different from what people have learned from reality. Generally, it is believed that rural producers are more vulnerable in terms of natural events that destroy their products and various kinds of government aid are delivered to producers. So what are the critical factors that make this difference?

One answer could be the alternative supply of agriculture product. The word “alternative” here is of special meaning. In the Arrow-Debreu economy, goods are identified by both time and place of being produced or being exchanged. In our existing models, agriculture products used for consumption are produced in the rural sector of this small economy in the same time period. Alternative supply in the context of our models means that, agriculture products for consumption of this period may be produced by a rural sector in a foreign country, in the same period or in the past, or they may be produced by the domestic rural sector in the past. In other words, this small economy may import agriculture product from the international market, or it can make inter-temporal storage of agriculture product for coming shocks. With the alternative supply, the fluctuation in the supply of domestically and newly produced agriculture products will have less impact on the market price and rural producers’ advantage may diminish.

In this sense, this chapter is to discuss the impact of grain reserve policy adopted in many countries on the re-allocation of disaster risk between rural and urban sectors. Technically, it refers to the second piece of explanation above that a part of the agriculture product supplied in the market may be produced by domestic rural sector in the past. Practically, it refers to government policies that try to stabilize grain price. The basic structure is that a government is obligated to buy up a part of market supply from producers when it is too abundant and producers may suffer from “harvest poor”. This amount of grain is then stored in granaries and prepared for coming shocks that may cause insufficient market supply. When some shocks occur and market supply is in short, the government puts the stored grain into the market to increase supply so that the price does not go too high for low-income individuals to afford. Although specific clauses are different across countries and districts, the basic structure is the same that it follows the “buffer-stock” strategy to smooth the supply across time periods.

It is of both academic and practical meaning to discuss this issue. Academically, grain reserve policy is a compound policy instrument that not only diversifies disaster risk along the time dimension but also re-allocates it between sectors. The first element is straightforward because “buffer-stock” strategy is adopted. Disaster risk is re-allocated because the grain reserve policy changes the relationship of state-contingent prices. Price gap between the lucky and unlucky states actually determines the degree of risk bearing of rural producers and urban workers, which shall be revealed in details later in this Chapter. Practically, by introducing the grain reserve policy, result of our model will have one step closer to the reality and more precise policy implications can be put forward. For instance, with the existence of grain reserve policy, is inter-sectoral monetary transfer still necessary to achieve economic efficiency?

The other scenario about international market will not be discussed in this thesis so that the manner of description is consistent with the previous chapters. When an international market is introduced, the model collapses to a partial equilibrium and domestic price for agriculture product converges to the one in the international market. As a result, domestic market price cannot play the role of allocating resources and risk-bearing, since it is not affected by domestic supply anymore. The model will lose one essential mechanism that has been working in previous two models.

The structure of the entire chapter is arranged as follows. In section 5.2, the benchmark case of the model is derived. In section 5.3 we discuss the social optimum in which the central planner determines everything of the economy. In section 5.4, government intervention in the form of grain reserve policy is discussed. It makes a sound explanation about the function in inter-generational diversification and inter-sectoral re-allocation of disaster risk. Section 5.5 gives numerical examples to compare across cases in terms of economic efficiency. In section 5.6 the discussion switches to a more practical manner. Government intervention beyond the grain policy is touched upon and again inter-sectoral fiscal transfer is discussed.

5.2 MODEL ASSUMPTIONS

The model in this chapter has succeeded the basic dual-economy structure. For the ease of formulation, Stone-Geary utility which also yields an inelastic demand system with respect to agriculture product takes the place of the quasi-linear utility function. The focus of discussion is when grain reserve policy is carried out, how disaster risks can be maximally financed, both inter-temporally and inter-sect orally. The agriculture product in this chapter refers to grains which are of lower perishing rate than fresh vegetables or fruits. Then the model assumes that the central government of this small economy establishes a number of barns to store grains produced domestically. Government storage is with advanced technique so that the perishing rate is extremely low and it also enables scale effect. In contrast, grain storage at household level is assumed to be very costly and rural producers simply do not make such kind of reserve.

5.3 THE BENCHMARK CASE

Ex post decision-making and equilibrium

The mode in this chapter uses exactly the same framework as the previous one except that the *ex post* direct utility function takes the Stone-Geary form. If we use $e_i(t)$ to denote the state-contingent total labor income of an individual of type *i*, with *i*=1, 2 denoting the rural producer and the urban worker, an individual's *ex post* optimization problem is to

$$\max_{x,y} u(x,y) = A\cdot\left(x_i(t)-\overline{x}\right)^{\alpha} y_i(t)^{1-\alpha}, 0<\alpha<1$$

such that

$$p(t)x_i(t)+y_i(t)=e_i(t), \text{ for both } t$$

In the utility function, parameter $A=\alpha^{-\alpha}(1-\alpha)^{\alpha-1}$ is used to simplify denotation. $\overline{x}$ is the subsistence level of consumption of the agriculture product. Optimal consumption bundle is very straightforward:

$$\begin{aligned} x_i^*(t) &= \overline{x}+\frac{\alpha}{p(t)}\left[e_i(t)-p(t)\overline{x}\right] \\ y_i^*(t) &= (1-\alpha)\left[e_i(t)-p(t)\overline{x}\right] \end{aligned}, \text{ for both } t \qquad (5.1)$$

The optimal consumption behavior implies that an individual firstly spend a part of the labor income, $p(t)\overline{x}$, to meet the subsistence level of consumption. This part of income is generally called "residual income" that is used for "residual consumption" (or subsistence consumption). Then the individual spends the non-residual part of income $e_i(t)-p(t)\overline{x}$ proportionally on agriculture product and urban goods, which is the basic feature of all C-D utility functions of degree one. *Ex post* indirect utility follows

$$v_i(t)=p(t)^{-\alpha}\left[e_i(t)-p(t)\overline{x}\right], \text{ for all } t \qquad (5.2)$$

In the context of our model, budget constraints in the benchmark case follow

$$\begin{aligned} e_1(t) &= p(t)\delta(t)X - C(X) \\ e_2(t) &= e_2 \end{aligned}, \text{ for both } t \tag{5.3}$$

The labor income of the rural producer comes from the profit of cropping while that of the urban worker comes from the wage paid by firms in the urban sector. The social aggregate budget constraints are

$$\begin{aligned} nx_1^*(t) + (1-n)x_2^*(t) &\le n\delta(t)X \\ ny_1^*(t) + (1-n)y_2^*(t) &\le (1-n)e_2 - nC(X) = Y \end{aligned}, \text{ for both } t \tag{5.4}$$

Y is used here as a simplified denotation of social aggregate urban goods for consumption. If still we assume that both markets are cleared period by period, the state-contingent relative price is

$$p(t) = \frac{\alpha}{1-\alpha}\frac{Y}{n\delta(t)X - \bar{x}}, \text{ for both } t, \tag{5.5}$$

which equals the ratio between social aggregation urban goods available for consumption and social aggregate agriculture products for non-subsistence consumption, times the elasticity of substitution between two types of goods.

Ex ante decision-making and equilibrium

For each individual, *ex ante* decision-making is to decide in which sector he/she is willing to work in the coming period. This structure again implies that the marginal worker is indifferent of working in either sector, that

$$\mathrm{E}\,W_1 = \mathrm{E}\,W_2 \tag{5.6}$$

with $\mathrm{E}\,W_i = \sum_t \pi(t)W\big(v_i(t)\big)$. Similarly, $W(\cdot)$ is the *ex ante* utility function in CRRA form. After an individual chooses sectors, rural producers think about their optimal investment behavior,

$$\max_X \mathrm{E}\,W_1 = \sum_t \pi(t)W\big(v_1(t)\big)$$

such that

$$v_1(t) = p(t)^{-\alpha}\Big[p(t)\big(\delta(t)X - \bar{x}\big) - C(X)\Big], \text{ for both } t \tag{5.7}$$

Since rural producers are assumed to be merely price takers of little market power, the necessary conditions for maximization is that $\partial^2\mathrm{E}\,W_1/\partial X^2 < 0$. It can be easily proved that necessary conditions hold for this problem when $C(X)$ is quasi-convex, $C'(X) > 0$ and $C''(X) \ge 0$. In this sense, the first-order condition for maximization is

$$\sum_t \pi(t)\frac{\partial W\big(v_1(t)\big)}{\partial X} = 0. \tag{5.8}$$

When we assume the *ex ante* utility function is CRRA of degree 1, (5.8) is equivalent to

$$\sum_t \pi(t) \frac{p(t)\delta(t) - C'(X)}{p(t)(\delta(t)X - \overline{x}) - C(X)} = 0\,, \tag{5.9}$$

Ex ante equilibrium $\left(X_b^*, n_b^*\right)$ can then be derived by solving (5.6) and (5.9).

5.4 SOCIAL OPTIMUM

5.4.1 Social optimum without grain reserve

In the social optimum, it is assumed that there is a wise central planner who determines every aspect of the economy. When no grain reserve is assumed, the central planner allocates resources and redistributes goods for consumption within the time period. In this sense, our social optimization problem is described as

$$\max_{\substack{X,n,x_1(t),x_2(t)\\ y_1(t),y_2(t)}} U = n\gamma_1 \sum_t \pi(t)\ln\left(u\left(x_1(t), y_1(t)\right)\right) + (1-n)\gamma_2 \sum_t \pi(t)\ln\left(u\left(x_2(t), y_2(t)\right)\right)$$

subject to:

$$\begin{aligned} &\lambda_x(t): nx_1(t) + (1-n)x_2(t) = n\delta(t)X \\ &\lambda_y(t): ny_1(t) + (1-n)y_2(t) = (1-n)e_2 - nC(X) \qquad \text{, for both } t \\ &\quad \phi{:}\sum_t \pi(t)\ln\left(u\left(x_1(t), y_1(t)\right)\right) = \sum_t \pi(t)\ln\left(u\left(x_2(t), y_2(t)\right)\right) \end{aligned} \tag{5.10}$$

In the objective function, *ex post* direct utility function is employed, as in social optimum there is no price system. γ_i is the weight that the central planner assigned to individual of type *i*. X and n together determine the allocation of resources for production, while $x_i(t)$ and $y_i(t)$ determine the redistribution of goods for consumption. First-order conditions for maximization are:

$$\begin{aligned} &x_1(t): \left[n\gamma_1 - \phi\right]\pi(t)\frac{1}{u_1(\cdot)}\frac{\partial u_1(\cdot)}{\partial x_1(t)} - \lambda_x(t)n = 0 \\ &x_2(t): \left[(1-n)\gamma_2 + \phi\right]\pi(t)\frac{1}{u_2(\cdot)}\frac{\partial u_2(\cdot)}{\partial x_2(t)} - \lambda_x(t)(1-n) = 0 \\ &y_1(t): \left[n\gamma_1 - \phi\right]\pi(t)\frac{1}{u_1(\cdot)}\frac{\partial u_1(\cdot)}{\partial y_1(t)} - \lambda_y(t)n = 0 \\ &y_2(t): \left[(1-n)\gamma_2 + \phi\right]\pi(t)\frac{1}{u_2(\cdot)}\frac{\partial u_2(\cdot)}{\partial y_2(t)} - \lambda_y(t)(1-n) = 0 \quad \text{, for both } t \\ &\quad X: \sum_t n\left[\lambda_x(t)\delta(t) - \lambda_y(t)C'(X)\right] = 0 \\ &\quad n: \gamma_1 \mathrm{E}\,W_1 - \gamma_2 \mathrm{E}\,W_2 = \sum_t \lambda_x(t)\left[x_1(t) - x_2(t) - \delta(t)X\right] \\ &\qquad + \sum_t \lambda_y(t)\left[y_1(t) - y_2(t) + e_2 + C(X)\right] \end{aligned} \tag{5.11}$$

The first four first-order conditions yield:

$$\frac{\partial u_1(\cdot)}{\partial x_1(t)}\bigg/\frac{\partial u_1(\cdot)}{\partial y_1(t)}=\frac{\partial u_2(\cdot)}{\partial x_2(t)}\bigg/\frac{\partial u_2(\cdot)}{\partial y_2(t)}=\frac{\lambda_x(t)}{\lambda_y(t)}, \text{ for both } t \tag{5.12}$$

which must be equivalent to the state-contingent relative price $p(t)$ in decentralized equilibria. Solving for ϕ, $\lambda_x(t)$ and $\lambda_y(t)$ we get:

$$\begin{aligned}\phi &= (1-n)n\frac{\gamma_1[x_2(t)-\overline{x}]-\gamma_2[x_1(t)-\overline{x}]}{n[x_1(t)-\overline{x}]+(1-n)[x_2(t)-\overline{x}]}\\ &= (1-n)n\frac{\gamma_1 y_2(t)-\gamma_2 y_1(t)}{ny_1(t)+(1-n)y_2(t)}\end{aligned}, \text{ for both } t \tag{5.13}$$

Equation (5.13) implies that ϕ does not depend on the collective state of the world. So it must hold that $(x_1(t)-\overline{x})/(x_2(t)-\overline{x})$ and $y_1(t)/y_2(t)$ are constants. Since the redistribution of each consumption bundle $(x_i(t), y_i(t))$ must meet the optimal choice of individuals, it follows that

$$\frac{x_1(t)-\overline{x}}{y_1(t)}=\frac{x_2(t)-\overline{x}}{y_2(t)}, \text{ for both } t$$

Meanwhile, *ex ante* equilibrium requires that the expected *ex ante* utility be equalized across individual groups. Therefore, it necessarily holds that:

$$\begin{aligned}x_1(t) &= x_2(t) = n\delta(t)X\\ y_1(t) &= y_2(t) = Y\end{aligned}, \text{ for both } t \tag{5.14}$$

It means that in the social optimum the central planner will redistribute each individual with one identical consumption bundle, which is called “per capita redistribution”. With the redistribution strategy, it follows that

$$\begin{aligned}\lambda_x(t) &= \pi(t)\alpha\frac{1}{n\delta(t)X-\overline{x}}[\gamma_1 n+(1-n)\gamma_2]\\ \lambda_y(t) &= \pi(t)(1-\alpha)\frac{1}{Y}[\gamma_1 n+(1-n)\gamma_2]\end{aligned}, \text{ for both } t \tag{5.15}$$

In this sense, social optimal per capita output level and the number of laborers allocated to the rural sector is determined by following two equations, respectively:

$$\sum\nolimits_t \pi(t)\left[\alpha\frac{\delta(t)}{n\delta(t)X-\overline{x}}-(1-\alpha)\frac{1}{Y}C'(X)\right]=0 \tag{5.16}$$

$$\begin{aligned}&\gamma_1 \mathrm{E}W_1-\gamma_2\mathrm{E}W_2+\sum\nolimits_t \pi(t)\alpha\frac{X\delta(t)}{n\delta(t)X-\overline{x}}[\gamma_1 n+(1-n)\gamma_2]\\ &-\sum\nolimits_t \pi(t)(1-\alpha)\frac{e_2+C(X)}{Y}[\gamma_1 n+(1-n)\gamma_2]=0\end{aligned} \tag{5.17}$$

5.4.2 Social optimum when inter-temporal storage of grain is possible

When there is some technology that allows inter-temporal storage of grain, the central planner has higher degree of power to decide both intra and inter-temporal redistribution of consumption bundles. Inter-temporal redistribution of consumption is finished with the "buffer-stock" strategy. The central planner constructs well functioning barns which prevent grains stored from perishing fast. With these barns, the central planner then can decrease or increase total amount of agriculture products consumed in a time period when a certain collective state of nature occurs. Suppose when a certain collective state of nature t occurs, the central planner decides to change (either reduce or increase) intra-period aggregate agriculture product for consumption by $g(t)$, the budget constraint regarding agriculture product changes to

$$nx_1(t) + (1-n)x_2(t) = n\delta(t)X + g(t), \text{ for both } t \tag{5.18}$$

Simultaneously, the central planner has to follow her budget constraint that the input and output of barns must be balanced, $\psi(\mathbf{g}) = 0$. The can be many forms of $\psi(\mathbf{g})$ according to factors taken into account with various scenarios and different levels of sophistication. In this model, we still keep our emphasis on inter-sectoral issues and leave the inter-temporal one for Chapter 6. So it is assumed here that the grain storage technology is perfect and the perishable rate of grain is 0. Meanwhile, we have to allow the central planner to be able to borrow grains from outside of this small economy to meet the contingent resource gap when storage is in short in some periods. In this sense, the budget constraint of the barn is

$$\psi(\mathbf{g}) = \sum_t \pi(t)g(t), \tag{5.19}$$

which simply implies that the expected storage level must equal 0. The budget constraint is the simplest but it does not change the essential result of our discussion. The central planner's optimization problem can be put as

$$\max_{\substack{X,n,x_1(t),x_2(t)\\ y_1(t),y_2(t),g(0),g(1)}} U = n\gamma_1\sum_t \pi(t)\ln\Big(u\big(x_1(t),y_1(t)\big)\Big) + (1-n)\gamma_2\sum_t \pi(t)\ln\Big(u\big(x_2(t),y_2(t)\big)\Big)$$

such that

$$\begin{aligned} &\lambda_x(t): nx_1(t) + (1-n)x_2(t) = n\delta(t)X + g(t) \\ &\lambda_y(t): ny_1(t) + (1-n)y_2(t) = (1-n)e_2 - nC(X) \\ &\quad \mu: \sum_t \pi(t)g(t) = 0 \\ &\quad \phi: \sum_t \pi(t)\ln\Big(u\big(x_1(t),y_1(t)\big)\Big) = \sum_t \pi(t)\ln\Big(u\big(x_2(t),y_2(t)\big)\Big) \end{aligned} \quad \text{, for both } t \tag{5.20}$$

First-order conditions for maximization are:

$$\begin{aligned}
&x_1(t):[n\gamma_1-\phi]\pi(t)\frac{1}{u_1(\cdot)}\frac{\partial u_1(\cdot)}{\partial x_1(t)}-\lambda_x(t)n=0\\
&x_2(t):[(1-n)\gamma_2+\phi]\pi(t)\frac{1}{u_2(\cdot)}\frac{\partial u_2(\cdot)}{\partial x_2(t)}-\lambda_x(t)(1-n)=0\\
&y_1(t):[n\gamma_1-\phi]\pi(t)\frac{1}{u_1(\cdot)}\frac{\partial u_1(\cdot)}{\partial y_1(t)}-\lambda_y(t)n=0\\
&y_2(t):[(1-n)\gamma_2+\phi]\pi(t)\frac{1}{u_2(\cdot)}\frac{\partial u_2(\cdot)}{\partial y_2(t)}-\lambda_y(t)(1-n)=0 \quad \text{, for both } t, \qquad (5.21)\\
&\quad X:n\sum\nolimits_t\left[\lambda_x(t)\delta(t)-\lambda_y(t)C'(X)\right]=0\\
&g(t):\lambda_x(t)-\mu\pi(t)=0\\
&\quad n:\gamma_1\mathrm{E}W_1-\gamma_2\mathrm{E}W_2=\sum\nolimits_t\lambda_x(t)\left[x_1(t)-x_2(t)-\delta(t)X\right]\\
&\qquad +\sum\nolimits_t\lambda_y(t)\left[y_1(t)-y_2(t)+e_2+C(X)\right]
\end{aligned}$$

which is very similar to the set in (5.11). Consequently, it still derives

$$\begin{aligned}
&x_1(t)=x_2(t)=n\delta(t)X+g(t)\\
&y_1(t)=y_2(t)=Y
\end{aligned}\quad \text{, for both } t, \qquad (5.22)$$

that the central planner still carries out “per capita” redistribution policy. Meanwhile,

$$\begin{aligned}
&\lambda_x(t)=\pi(t)\alpha\frac{1}{n\delta(t)X-\overline{x}+g(t)}\left[\gamma_1 n+(1-n)\gamma_2\right]\\
&\lambda_y(t)=\pi(t)(1-\alpha)\frac{1}{Y}\left[\gamma_1 n+(1-n)\gamma_2\right]
\end{aligned}\quad \text{, for both } t \qquad (5.23)$$

The first-order condition with respect to $g(t)$ and (5.23) imply that

$$\mu=\alpha\frac{\gamma_1 n+(1-n)\gamma_2}{n\delta(t)X-\overline{x}+g(t)}\text{, for both } t \qquad (5.24)$$

Since μ is not contingent on the state of the world, it must hold that:

$$n\Delta X=g(1)-g(0) \qquad (5.25)$$

with $\Delta X=[\delta(0)-\delta(1)]X$ denoting the difference of output in the lucky and unlucky states. Optimal inter-temporal allocation of grain $\mathbf{g}_s^*$ follows

$$\begin{aligned}
&g_s^*(1)=\pi(0)n\Delta X\\
&g_s^*(0)=-\pi(1)n\Delta X
\end{aligned} \qquad (5.26)$$

With this strategy, disaster risk will be perfectly diversified across time periods. Social aggregate grain for consumption in any arbitrary period or state is the same,

$$n\delta(t)X+g_s^*(t)=n\mathrm{E}\tilde{\delta}X\text{, for both } t,$$

with $\mathrm{E}\tilde{\delta} = \sum_t \pi(t)\delta(t)$. In this sense, individuals' consumption bundles and *ex post* utility level become risk-free:

$$\begin{aligned} x_1(t) &= x_2(t) = n\mathrm{E}\tilde{\delta}X \\ \lambda_x(t) &= \pi(t)\alpha\frac{1}{n\mathrm{E}\tilde{\delta}X - \overline{x}}\left[\gamma_1 n + (1-n)\gamma_2\right] \end{aligned}, \text{ for both } t \tag{5.27}$$

So finally the social optimal choice (X_s^*, n_s^*) is determined by

$$\begin{aligned} \alpha\frac{\mathrm{E}\tilde{\delta}}{n\mathrm{E}\tilde{\delta}X - \overline{x}} - (1-\alpha)\frac{C'(X)}{Y} = 0 \\ \gamma_1\mathrm{E}W_1 - \gamma_2\mathrm{E}W_2 + \left[\gamma_1 n + (1-n)\gamma_2\right]\left[\alpha\frac{\mathrm{E}\tilde{\delta}X}{n\mathrm{E}\tilde{\delta}X - \overline{x}} - (1-\alpha)\frac{e_2 + C(X)}{Y}\right] = 0 \end{aligned} \tag{5.28}$$

5.5 DECENTRALIZED EQUILIBRIUM UNDER GOVERNMENT INTERVENTION

The social optimum provides us with the ideal and first-best allocation as reference. As in reality there is no such wise and powerful central planners, we switch our discussion to government intervention. Suppose there is a central government which cares the well-being of all its citizens and the development of this small economy. It can choose various kinds of grain policies attaching to the market mechanism to allocate resources and redistribute wealth for consumption.

5.5.1 Social insurance system

The central government has two means to provide full-cover social insurance to individuals. The one is to impose tax and give subsidy in the form of grain, while the other is to impose income tax and buy/sell grains in the market.

1) Grain tax and subsidy

In this system, the government imposes tax on rural producers in the form of grains when there is no disaster, while give them grain subsidy when disaster happens. This is similar to "Chinese type". Before the 1990s in China, with the Household Responsibility System (HRS), rural producers are obligated to hand a proportion of the harvest to the state. When disaster happens, they can get disaster aid in terms of stored grain. The scenario is similar the issue one we are discussing but the purpose of the Chinese grain policy during that period is different. Given the scenario described above, rural producers' income changes to

$$e_1(t) = p(t)\left[\delta(t)X - \overline{x} + \frac{g(t)}{n}\right] - C(X), \text{ for both } t,$$

which means that each rural producer pay the tax of $g(t)/n$ and in total the government changes the social aggregate supply of grain by $g(t)$. Consequently, the state-contingent effective price of the rural good can be detected as:

$$p(t)=\frac{\alpha}{1-\alpha}\frac{Y}{n\delta(t)X-\overline{x}+g(t)}\text{, for both } t \tag{5.29}$$

while the price of the urban goods does not change. The budget constraint for the government, in the simplest manner, still follows (5.19). When the government adopts the intervention strategy that is equivalent to the inter-temporal redistribution strategy of the central planner in (5.26), the intervention system exactly leads to the social optimum. All state-contingent labor incomes and relative prices become risk-free.

2) Income tax and subsidy

In this case, it is assumed that the government collects grain for reserve through buying up from the market, and increase market supply by selling grains in barns. The financial resources for buying up is supposed to be from state-contingent lamp-sum tax uniformly imposed to individuals, $\tau(t)$. In this sense, individuals' optimal choice switch to

$$\begin{aligned} x_i^{*\prime}(t) &= \overline{x}+\frac{\alpha}{p(g(t))}\left[e_i(t)-p(g(t))\overline{x}+\tau(t)\right] \\ y_i^{*\prime}(t) &= (1-\alpha)\left[e_i(t)-p(g(t))\overline{x}+\tau(t)\right] \end{aligned}\text{, for both } t \tag{5.30}$$

Two goods markets are described as:

$$\begin{aligned} nx_1^{*\prime}(t)+(1-n)x_2^{*\prime}(t) &= n\delta(t)X+g(t) \\ ny_1^{*\prime}(t)+(1-n)y_2^{*\prime}(t) &= (1-n)e_2-nC(X)=Y \end{aligned}\text{, for both } t \tag{5.31}$$

It is worth noting that the sign of $\tau(t)$ and $g(t)$ should be the same. Suppose in some state T the government sells the reserved grain to the market and makes positive revenue, $g(T)>0$. The revenue $p(T)g(T)$ is then used to pay back to individuals and therefore it is a kind of subsidy, $\tau(T)>0$. In other words, when the government reduces market supply of grain, it simultaneously reduces urban goods for consumption. The budget constraint for the government is

$$\tau(t)=p(t)g(t)\text{, for all } t\text{, and } \sum_t \pi(t)g(t)=0 \tag{5.32}$$

The only difference to the previous model is the existence of $g(t)$ which is the government demand when it is negative, or vice versa. State-contingent relative price(s) is not changed and follows equation (5.29). When the government clears its budget, it is equivalent to have the intervention strategy as the previous case, following equation (5.26). Consequently, this system also leads to social optimum.

5.5.2 Crop disaster insurance market under government intervention

Government intervention strategy

Suppose the central government wants to further reduce its influence and have more jobs done by the market. A common approach is that the government joins the system purely as a player in the market. It increases or reduces the market supply by merely selling grains to or buying up from the market. The financial resources held by the government come only from the difference of buying and selling, without imposing any tax or giving any subsidy in any form. In other words, the government follows "non-arbitrage transaction", starting from nothing and operating purely by borrowing, repaying, buying, and selling. In this sense, social aggregate budget constraints follow

$$\begin{array}{l} nx_1^*(t) + (1-n)\,x_2^*(t) = n\delta(t)\,X + g(t) \\ ny_1^*(t) + (1-n)\,y_2^*(t) = Y - p\big(g(t)\big)\,g(t) \end{array}, \text{ for both } t \qquad (5.33)$$

When the government buy $g(t)$ from the market, it simultaneously increases the urban goods available for consumption by $-p\big(g(t)\big)g(t)$. Since the government follows non-arbitrage transaction, individuals' budget constraints do not change with this intervention policy. Therefore, state-contingent efficient relative prices are

$$p\big(g(t)\big) = \frac{\alpha Y}{(1-\alpha)\big[n\delta(t)\,X - \overline{x}\big] + g(t)}, \text{ for both } t \qquad (5.34)$$

It is worth noting that price determined under this grain reserve policy is different from the one determined under full-cover social insurance system. In (5.29), the denominator of the second item is exactly the social aggregate rural goods available for non-subsistence consumption. When the government policy perfectly diversifies the risk to the time dimension, it becomes a constant. In (5.34), the denominator is not proportionate to social aggregate rural goods available for non-subsistence consumption. Even if the supply is a constant, the price is not a constant.

There can be two sets of budget constraints for the government to follow. Each corresponds to a specific scenario of diversifying the risk. The set refers to substantial budget constraint is

$$\sum\nolimits_t \pi(t)\,g(t) \ge 0 \text{ and } \sum\nolimits_t \pi(t)\,p(t)\,g(t) \ge 0\,. \qquad (5.35)$$

It implies the scenario that the government uses grain stored in barns as inter-temporal intermediate to diversify the risk. The first item denotes the substantial balance in grain barns while the second refers to its monetary budget in terms of urban goods. In lucky periods the government uses urban goods in hand (at the beginning it has to borrow from somewhere) to buy grain from the market and increase the storage, while in unlucky periods it sells grain to the market and offsets its deficit in urban goods. So budget balance requires that in the long run grain stored in barns must not go into negative amount and the government must not be in debt. The implicit assumption behind is that the grain kept in barns are well protected so that they are perishing at extremely low rate.

Meanwhile, it is also assumed that the government has external sources to borrow grains when contingently domestic grain in barn is not able to change the price to the desirable degree.

The other budget set referring to international transaction is

$$\sum_t \pi(t)[p(t)-\hat{p}]g(t) \geq 0\,, \tag{5.36}$$

in which $\hat{p}$ is the price in the international market. With this budget set, it is implicitly assumed that the government can access to the international grain market. It uses urban goods, which is assumed to be the value-keeping asset in economic models, as the intermediate to diversify the risk. In lucky periods, the government buys grains from the domestic market and sells them to the international market, making a balance of $[p(0)-\hat{p}]g(0)$, in which $g(0)<0$. In unlucky periods, the government uses the sales revenue to buy grains from the international market and then sell in the domestic market, making a balance of $[p(1)-\hat{p}]g(1)$ with $g(1)>0$. This intervention strategy can work only when the price in the international market is either lower or higher than both domestic prices in the lucky and unlucky states, $\hat{p}<p(0)<p(1)$ or $\hat{p}>p(1)>p(0)$. In the long run, the government must not be in negative balance and so we have (5.36).

The rest part of this chapter is devoted to the discussion following budget set (5.35)[1]. Given the intervention strategy corresponding to budget set (5.35), what is the impact of the intervention on the market price and the risk-allocation between sectors? The mechanism inside is revealed in Fig. 5-1 and 5-2.

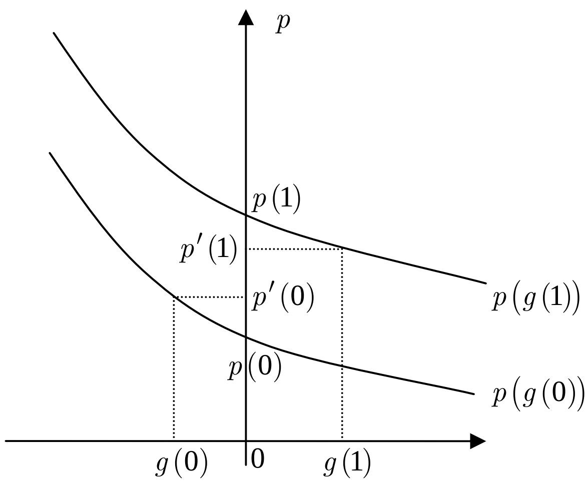


Fig. 5-1 The impact of government intervention on state-contingent prices

[1] Both scenarios have some trade-offs. With (5.35), the model keeps its general equilibrium structure. The drawback of the story is that one has to assume the government has such advanced storage technology that grains do not perish at all in barns. With (5.36), urban goods is used as the intermediate for inter-temporal value-keeping method, which is assumed to be with very low discount rate in economic models. Nevertheless, the model collapses to a partial equilibrium and the viability of the method largely depends on the price in the international market. In order to keep the consistency of this thesis, the author has decided not to open the international grain market and rule out the scenario corresponding to (5.36). The strong assumption for (5.35) can be relaxed by formulating the dynamic process of input, output and perishing process of grain. Actually, Chapter 6 has put sound discussion regarding dynamic buffer-stock strategy with stochastic process model.

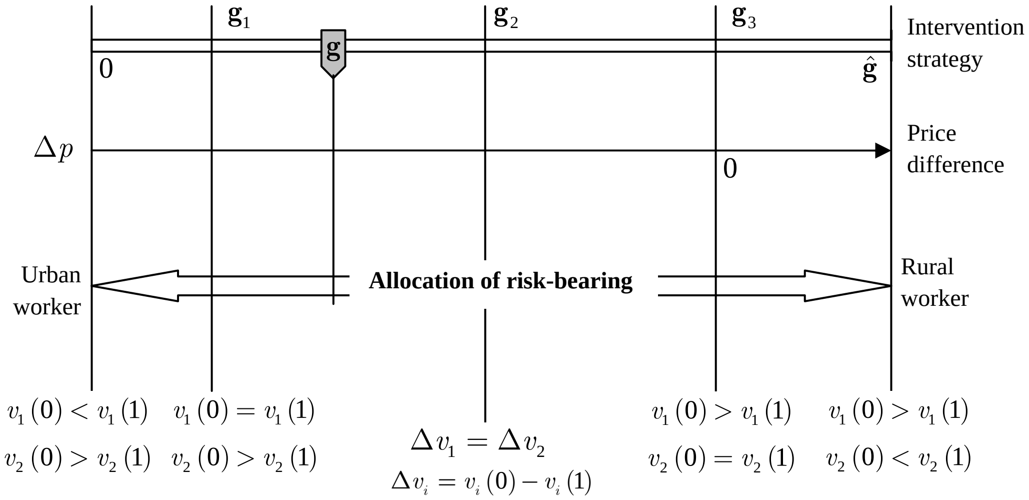


Fig. 5-2 The impact of government intervention on disaster risk allocation between sectors

The primary impact of government intervention is the price difference in the lucky state and the unlucky state. In Fig. 5-1, the horizontal axis denotes the intervention strategy, the amount of grain that the government buys from or sells to the market. The vertical axis is the price. According to (5.34), state-contingent relative price is a convex set with respect to the intervention vector

$$\frac{\partial p(g(t))}{\partial g(t)} < 0 < \frac{\partial^2 p(g(t))}{\partial g(t)^2}.$$

According to the benchmark *ex post* equilibrium, relative price in the lucky state is lower than the one in the unlucky state, $p(0) < p(1)$. In this sense, the price gap $\Delta p = p(0) - p(1)$ is negative. If the government wants to narrow the negative gap or even wants to create positive price gap, it must decrease market supply in lucky periods, $g(0) < 0$, and increase market supply in unlucky periods, $g(1) > 0$. With the intervention, the price in lucky periods goes up from $p(0)$ to some $p(0)'$ in Fig. 5-1. On the other hand, the price in unlucky periods drops down from $p(1)$ to $p(1)'$ in Fig. 5-1. The government can change the price gap to any value by choosing intervention vector $\mathbf{g}$ following the budget set of (5.35).

Then we discuss the relationship between the government intervention and the risk allocation between sectors. In Fig. 5-2, there are three horizontal axes. The one at the top denotes the government intervention strategy $\mathbf{g}$, following budget set (5.35). Here we use a slider on a bar to depict the intervention, as the system performs like a balance with the government in control. By moving the slider on the bar, the government exactly determines which group of individuals bears more risk. The axis in the middle represents the price gap, $\Delta p = p(g(0)) - p(g(1))$. The last horizontal axis represents the risk allocation between the rural and urban sectors. For any arbitrary intervention strategy $\mathbf{g}$ there is a unique corresponding price gap. With this price gap, the difference between *ex post* welfare states of the rural producer and the urban worker is determined.

There are some critical vectors of government intervention strategy. When no intervention is carried out, it corresponds to the benchmark case in which rural producers love the arrivals of disasters, $v_1(0) < v_1(1)$. At $\mathbf{g}_1$, $\Delta p(\mathbf{g}_1)$ exactly allows the rural producer to be risk free with $v_1(0) = v_1(1)$. When the intervention goes to $\mathbf{g}_3$, $\Delta p(\mathbf{g}_3) = 0$ and in this sense the urban worker becomes risk free with $v_2(0) = v_2(1)$ while the rural producer is bearing all the risk, $v_1(0) > v_1(1)$. From $\mathbf{g}_1$ to $\mathbf{g}_3$ there must exist an intervention strategy $\mathbf{g}_2$ such that the rural producer and the urban worker are equivalent in terms of disaster risk, with $\Delta v_1 = \Delta v_2$ ($\Delta v_i = v_i(0) - v_i(1)$). Since the migration or labor allocation equilibrium requires that $\mathrm{E}\,W_1 = \mathrm{E}\,W_2$, it is equivalent to put $v_1(t) = v_2(t)$ for both *t* at $\mathbf{g}_2$.

Since $\mathbf{g}_2$ corresponds to the risk-equivalent point, when $\mathbf{g} \in [0, \mathbf{g}_2)$, rural producers are advantageous in terms of disaster risk, $\Delta v_1 < \Delta v_2$. Technically they can offer disaster insurance coverage to urban workers. But of course it is not so realistic and it cannot be the "crop disaster insurance". Particularly, on the segment $\mathbf{g} \in [0, \mathbf{g}_1)$ we say that rural producers are beneficiaries of disaster risk, as they are in higher welfare state in the unlucky state. When $\mathbf{g} \in [\mathbf{g}_2, \hat{\mathbf{g}})$, risks are shifted back from urban workers to rural producers and therefore urban workers become advantageous in terms of disaster risk. Then they can offer crop disaster insurance to rural producers. Particularly, on the segment $\mathbf{g} \in (\mathbf{g}_3, \hat{\mathbf{g}})$ urban workers become the beneficiaries of disaster risk.

So this is how the government intervention into the grain market works both inter-temporally and inter-sectorally. When it diversifies the risk along the time dimension, it simultaneously changes the relationship between state-contingent relative prices. The change in the price pattern then affects state-contingent welfare states of individuals and finally determines the degree of risk-bearing. When the price gap Δp increases from negative to positive, disaster risk is gradually shifted from urban workers to rural producers. This last thing worth mentioning here is that the benchmark $\mathbf{g} = 0$ could lay to either side of $\mathbf{g}_1$, depending on specification of parameters. Note that the mechanism derived here also applies for Quasi-linear utility function which has been used in Chapter 4.

Crop disaster insurance equilibrium under arbitrary intervention strategies

As we have seen in Fig. 5-2, when $\mathbf{g} \in [\mathbf{g}_2, \hat{\mathbf{g}})$, urban workers can offer crop disaster insurance to rural producers. Our interest is whether the crop disaster insurance market under this government intervention can achieve social optimum. It is natural to address this question as in all cases market mechanism is more favorable than centralized approaches if they derive equivalent results. To reveal the answer, firstly we derive the crop disaster insurance market equilibrium, assuming that the government conducts a certain intervention policy $\mathbf{g} \in [\mathbf{g}_2, \hat{\mathbf{g}})$. With the result, the optimal intervention strategy of the government will be derived in the next sub-section.

Suppose now the government is conducting a certain intervention policy, $\mathbf{g} = (g(0), g(1))$, which enables urban workers to offer crop disaster insurance to rural producers. In this sense, rural producers' insurance demand behavior is determined by following optimization program

$$\max_{X,m_1} \mathrm{E}\, W_1 = \sum_t \pi(t) W\left(v_1\left(p\left(g(t)\right), \omega_1(t)\right)\right)$$

subject to:

$$\begin{aligned} \lambda_1(0) &: \omega_1(0) = e_1'(0) - \nu m_1 \\ \lambda_1(1) &: \omega_1(1) = e_1'(1) + (1-\nu) m_1 \end{aligned} \tag{5.37}$$

$e_1'(t) = p(g(t))(\delta(t) X - \overline{x}) - C(X)$ is the labor income for non-subsistence consumption of a rural producer. $\omega_1(t)$ is the final state-contingent economic value of goods that is consumed by a rural producer. Note that $m_1 > 0$ so that the insurance is truly crop disaster insurance that is offered by the urban workers to the rural producers. First-order conditions for optimization are:

$$\pi(t) \frac{dW\left(v_1(t)\right)}{dv_1(t)} \frac{\partial v_1(t)}{\partial \omega_1(t)} = \lambda_1(t), \text{ for both } t \tag{5.38}$$

$$\sum_t \lambda_1(t)\left(p\left(g(t)\right)\delta(t) - C'(X)\right) = 0 \tag{5.39}$$

$$-\lambda_1(0)\nu + \lambda_1(1)(1-\nu) = 0 \tag{5.40}$$

Then the optimal investment in producing rural good $X^* = X(\mathbf{g})$ is determined by

$$(1-\nu) p\left(g(0)\right)\delta(0) + \nu p\left(g(1)\right)\delta(1) = C'(X) \tag{5.41}$$

and the optimal insurance demand is determined by:

$$m_1(\nu) = \frac{\pi(1)(1-\nu) e_1'(0) - \pi(0)\nu e_1'(1)}{\nu(1-\nu)} \tag{5.42}$$

On the other hand, insurance supply behavior of the urban workers is to meet the optimization program

$$\max_{m_2} \mathrm{E}\, W_2 = \sum_t \pi(t) W\left(v_2\left(p\left(g(t)\right), \omega_2(t)\right)\right)$$

subject to:

$$\begin{aligned} \lambda_2(0) &: \omega_2(0) = e_2'(0) + \nu m_2 \\ \lambda_2(1) &: \omega_2(1) = e_2'(1) - (1-\nu) m_2 \end{aligned} \tag{5.43}$$

Similarly, $e_2'(t) = e_2 - p(g(t))\overline{x}$ is the labor income for non-subsistence consumption of the urban worker. This optimization problem yields:

$$m_2(\nu) = \frac{\pi(0)\nu e_2'(1) - \pi(1)(1-\nu) e_2'(0)}{\nu(1-\nu)} \tag{5.44}$$

The premium rate ν is endogenously determined to clear the insurance market:

$$nm_1(\nu) = (1-n)\, m_2(\nu) \tag{5.45}$$

Simultaneously, the migration stops when

$$\sum\nolimits_t \pi(t) \ln\left(p(g(t))^{-\alpha}\, \omega_1(t)\right) = \sum\nolimits_t \pi(t) \ln\left(p(g(t))^{-\alpha}\, \omega_2(t)\right), \tag{5.46}$$

which is equivalent to

$$\sum\nolimits_t \pi(t) \ln \omega_1(t) = \sum\nolimits_t \pi(t) \ln \omega_2(t) \tag{5.47}$$

So the equilibrium $(X(\mathbf{g}), \nu(\mathbf{g}), n(\mathbf{g}))$ can be derived by solving equations (5.41), (5.45) and (5.46). Some relationships can be directly derived without solving the problem .Firstly,

$$\frac{\lambda_1(0)}{\lambda_1(1)} = \frac{1-\nu}{\nu} = \frac{\lambda_2(0)}{\lambda_2(1)},$$

which means that the marginal expected *ex ante* utility with respect to income is proportionate between rural producers and urban workers in each collective state *t*. It is equivalent to hold

$$\frac{\omega_1(0)}{\omega_2(0)} = \frac{\omega_1(1)}{\omega_2(1)}$$

With the necessary condition for *ex ante* equilibrium (5.47), it is deduced that

$$\omega_1(t) = \omega_2(t) = \Omega(t)\text{, for both } t \tag{5.48}$$

As we know, social aggregate economic value of goods for non-subsistence consumption is

$$\begin{aligned}\Omega(t) &= n\omega_1(t) + (1-n)\,\omega_2(t) = p(g(t))\left[n\delta(t)X - \overline{x}\right] + Y \\ &= \frac{n\delta(t)X - \overline{x} + g(t)}{(1-\alpha)\left[n\delta(t)X - \overline{x}\right] + g(t)} Y = q(g(t))\, Y\end{aligned}\text{, for both } t \tag{5.49}$$

In this sense, equation (5.45) yields

$$\begin{aligned}\nu &= \frac{\pi(1)\left[ne_1'(0) + (1-n)\,e_2'(0)\right]}{\pi(0)\left[(1-n)\,e_2'(1) + ne_1'(1)\right] + \pi(1)\left[ne_1'(0) + (1-n)\,e_2'(0)\right]} \\ &= \frac{\pi(1)\,\Omega(0)}{\pi(0)\,\Omega(1) + \pi(1)\,\Omega(0)}\end{aligned} \tag{5.50}$$

In the benchmark case where $g(t) = 0$ and $\Omega(0) = \Omega(1)$, the economic value of social aggregate agriculture goods for non-subsistence consumption is preserved. This is a feature that Stone-Geary utility function has succeeded from C-D utility functions. Meanwhile, the premium rate equals the probability of the event which is believed to be the fair rate. The insurance, however, is not valid in terms of crop disaster insurance because in this case rural producers are suppliers while urban workers are demanders.

So finally the population distribution pattern is determined by

$$\frac{n}{1-n}=\frac{m_2}{m_1}\rightarrow n=\frac{m_2}{m_1+m_2}=\frac{\Omega(0)-e_2'(0)}{e_1'(0)-e_2'(0)} \tag{5.51}$$

Therefore, the crop disaster insurance equilibrium can also be determined by solving equations (5.41), (5.50) and (5.51).

Optimal intervention strategy

After observing the equilibria corresponding to all feasible intervention strategies, the government can choose the optimal one so that individuals' expected *ex ante* utility is maximized.

$$\begin{aligned}\max_{\mathbf{g}} \mathrm{E}\,W_i^* &= \sum\nolimits_t \pi(t) W\left(p\left(g(t)\right),\Omega(t)\right)\\ &= -\alpha\sum\nolimits_t \pi(t)\ln\left(p\left(g(t)\right)\right)+\sum\nolimits_t \pi(t)\ln\left(q\left(g(t)\right)\right)+\sum\nolimits_t \pi(t)\ln Y\end{aligned}$$

such that

$$\begin{aligned}&\eta_1: -\sum\nolimits_t \pi(t) g(t)\le 0\\ &\eta_2: (1-\nu)p\left(g(0)\right)\delta(0)+\nu p\left(g(1)\right)\delta(1)-C'(X)=0\\ &\eta_3: nm_1(\nu)-(1-n)m_2(\nu)=0\\ &\eta_4: \sum\nolimits_t \pi(t)\ln\omega_1(t)-\sum\nolimits_t \pi(t)\ln\omega_3(t)=0\\ &\eta_5: -\sum\nolimits_t \pi(t)p\left(g(t)\right)g(t)\le 0\end{aligned}, \tag{5.52}$$

If we denote the functions corresponding to Lagrangian multiplier 1,2,…,5 by $f_i(\cdot)$, *i*=1, 2, …, 5, the Lagrange can be established as

$$\mathcal{L}\left(X,\mathbf{g},n,\nu,\eta_1,\eta_2,\eta_3,\eta_4,\eta_5\right)=\mathrm{E}\,W_i-\eta_1 f_1(\cdot)-\eta_2 f_2(\cdot)-\eta_3 f_3(\cdot)-\eta_4 f_4(\cdot)-\eta_5 f_5(\cdot)$$

and first-order conditions are

$$\begin{aligned}&\frac{\partial\mathcal{L}}{\partial X},\frac{\partial\mathcal{L}}{\partial\nu},\frac{\partial\mathcal{L}}{\partial n},\frac{\partial\mathcal{L}}{\partial g(0)},\frac{\partial\mathcal{L}}{\partial g(1)},\eta_1 f_1(\cdot),f_2(\cdot),f_3(\cdot),f_4(\cdot),\eta_5 f_5(\cdot)=0\\ &\eta_1\ge 0, f_1(\cdot)\le 0,\eta_5\ge 0, f_5(\cdot)\le 0\end{aligned}$$

Equivalently, the Lagrange can be set up as

$$\mathcal{L}^1\left(\mathbf{g},n,\nu,\eta_1,\eta_3,\eta_4,\eta_5\right)=\mathrm{E}\,W_i-\eta_1 f_1(\cdot)-\eta_3 f_3(\cdot)-\eta_4 f_4(\cdot)-\eta_5 f_5(\cdot),$$

without taking individuals' first-order condition with respect to optimal output level into account. It follows the implication of envelop theorem. In this sense, the optimal intervention strategy is to solve

$$\frac{\partial\mathcal{L}^1}{\partial\nu},\frac{\partial\mathcal{L}^1}{\partial n},\frac{\partial\mathcal{L}^1}{\partial g(0)},\frac{\partial\mathcal{L}^1}{\partial g(1)},\eta_1 f_1(\cdot),f_2(\cdot),f_3(\cdot),f_4(\cdot),\eta_5 f_5(\cdot)=0$$
$$\eta_1\geq 0,f_1(\cdot)\leq 0,\eta_5\geq 0,f_5(\cdot)\leq 0$$

Qualitatively, we are interested in whether this first-best crop insurance market can lead to the social optimal allocation of risk and resources. According to the social optimum, the optimal inter-temporal diversification of disaster risk requires to stabilize market supply of grains that $n\delta(t)X+g(t)$ is kept as a constant and the intervention strategy must follow (5.26). If the government follows this intervention strategy, according to (5.34), it simultaneously holds that $p(g(0))>p(g(1))$. In this sense, the monetary budget constraint of the government binds and social optimal diversification of disaster risk is not a feasible redistribution with this policy. The intervention strategy must bind at the monetary constraint. The feasible policy is let

$$\sum\nolimits_t \pi(t)g(t)=0 \text{ and } \sum\nolimits_t \pi(t)p(g(t))g(t)=0$$

which directly yields that

$$\begin{aligned} g(1)&=(1-\alpha)\pi(0)n\Delta X\\ g(0)&=-(1-\alpha)\pi(1)n\Delta X \end{aligned}. \tag{5.53}$$

With this intervention policy, disaster risk is not fully diversified to the time-dimension and state-contingent market supply of grain is not constant. Intervention strategy in (5.53) is then called the “budget-viable” intervention under non-arbitrage transaction assumption. With this policy, the state-contingent relative price of grain becomes a constant

$$p(g(0))=p(g(1))=\frac{\alpha Y}{(1-\alpha)n\mathrm{E}\tilde{\delta}X}.$$

Technically, the result of imperfect diversification is resulted by the intervention strategy of “non-arbitrage transaction”. Nevertheless, the author believes that it reflects the reality to some extent as in may policy documents governments are mentioning “to stabilize the grain price across states/ years”, as price is the signal that can be observed in the easiest manner. Meanwhile, governments do not specifically collects tax revenue or give subsidy according to the collective state of the world, while they do establish grain reserves (barns) to store grain for multi-periods to stabilize the market price of grain. In the social insurance system, it is equivalent to stabilize cross-states market supply and cross-states market price. In this intervention system where crop disaster insurance market is supposed to play its role, two “stabilizing” diverges. This system can only lead to second-best equilibrium in terms of individuals’ welfare states.

5.6 NUMERICAL EXAMPLES AND EFFICIENCY ISSUES

Numerical examples

The efficiency performances of the benchmark equilibrium, social optimum and crop disaster insurance market equilibrium under government grain intervention are compared in this section with numerical examples. We give following specification,

$$\pi(0)=\pi(1)=1/2,\ \delta(0)=1,\ \delta(1)=1/3,\ \alpha=1/2,\ \overline{x}=1,\ C(X)=X^2/10,$$

and the wage rate in the urban sector e_2 as parameters, numerical results are derived. The gradually increasing e_2 represents the scenario that the urban sector is growing with increasing wage rates paid to urban workers. The numerical results for the benchmark case are

Table 5-1 Numerical results of benchmark equilibria

e_2	X_b^*	n_b^*	$p(0)$	$p(1)$	$v_1(0)$	$v_1(1)$	$v_2(0)$	$v_2(1)$	$\mathrm{E}W_i$
30	15.586	0.347	2.54	13.98	8.02	9.19	17.22	4.24	2.150
40	18.607	0.326	3.10	15.39	11.35	11.58	20.95	6.27	2.439
50	21.178	0.314	3.59	16.67	14.54	13.76	24.50	8.16	2.649
60	23.457	0.306	4.02	17.86	17.62	15.80	27.91	9.97	2.814
70	25.527	0.300	4.42	18.97	20.60	17.74	31.18	11.72	2.950

It can be observed in the table that the rural producer is truly advantageous in terms of disaster risk, $p(0)<p(1)$, $\Delta v_1<\Delta v_2$. When $e_2=30$ and 40, we have $v_1(0)<v_1(1)$ such that rural producers are beneficiaries of disaster risks. If individuals are assumed to be risk averse, insurance coverage can only be sold from the rural producer to the urban worker. Crop disaster insurance is unnecessary because rural producers are beneficiaries of disaster risk. This result is consistent with the result of the model in Chapter 4.

As for the social optimum, we have to apply the necessary condition for consistency between the centralized approach and decentralized approach

$$\gamma_i=\frac{1}{\lambda_i}=\frac{1}{\sum_t \pi(t)\dfrac{dW(v_i(\cdot))}{dv_i(\cdot)}\dfrac{dv_i(\cdot)}{d\omega_i(\cdot)}},$$

that the weight corresponding to individual group *i* equals the reverse of the marginal expected utility with respect to state-contingent wealth for consumption. It can be seen in the insurance case that it necessarily holds that $\gamma_1=\gamma_2$. In this sense, numerical results are put in Table 5-2.

From the numerical results it can be found that, in the social optimum, the central planner exactly smoothes the grain supply perfectly across both states by using the grain reserve. For each set of result, the intervention vector exactly follows (5.26). Individuals of both groups enjoy identical and risk-free *ex post* consumption bundles and therefore have the same level of welfare.

Table 5-2 Numerical results of social optima

e_2	X_s^*	n_s^*	$g(0)$	$g(1)$	$v_i(t)$	$\mathrm{E}W_i$
30	17.321	0.293	-1.693	1.693	12.93	2.562
40	20.000	0.288	-1.917	1.917	16.15	2.782
50	22.361	0.284	-2.113	2.113	19.13	2.951
60	24.495	0.281	-2.291	2.291	21.97	3.090
70	26.458	0.278	-2.455	2.455	24.69	3.206

The numerical results of the insurance case are put in Table 5-3. Firstly it is assumed that the government exactly follows the perfect diversification strategy without considering monetary budget constraint.

Table 5-3 Numerical results of insurance equilibria under optimal intervention

e_2	$X^*(\mathbf{g})$	$n^*(\mathbf{g})$	$g(0)$	$g(1)$	ν	m_1	m_2
30	17.321	0.293	-1.693	1.693	0.855	206.5	85.7
40	20.000	0.288	-1.917	1.917	0.838	247.3	99.8
50	22.361	0.284	-2.113	2.113	0.825	289.8	114.7
60	24.495	0.281	-2.291	2.291	0.820	332.9	129.9
70	26.458	0.278	-2.455	2.455	0.814	376.2	145.1
e_2	$p(0)$	$p(1)$	$v_i(0)$	$v_i(1)$	$\mathrm{E}W_i$	$\sum_t \pi(t)\,p(t)\,g(t)$	
30	17.89	3.04	20.19	8.32	2.562	-25.1411	
40	18.55	3.58	24.40	10.72	2.783	-28.6859	
50	19.44	4.05	28.46	12.99	2.956	-32.5209	
60	20.39	4.48	32.35	15.17	3.098	-36.4444	
70	21.33	4.88	36.11	17.26	3.217	-40.3927	

In this case, the optimal intervention strategy follows fully inter-temporal diversification that the state-contingent supplies are kept as constant (the intervention strategy exactly holds (5.26), which is the full diversification). State-contingent relative prices of rural goods to urban goods follow $p(g(0)) > p(g(1))$. All intra-temporal risks are shifted back to rural producers. In this sense, domestic crop insurance market is viable and it plays the role of redistributing wealth and risk according to the collective state. Insurance equilibrium requires that all groups of individual have identical *ex post* welfare states.

It is interesting to observe that individuals' welfare level is even higher than the social optimal one. The key is that with this intervention strategy the budget set of the government is not closed. Since $p(g(0)) > p(g(1))$ and $\sum_t \pi(t)\,g(t) = 0$, it follows that $\sum_t \pi(t)\,p(g(t))\,g(t) < 0$. With this intervention strategy the government will be in negative monetary balance. In other words, this set of equilibria implicitly assumes that the government has extra resources which are not available in this dual-economy system. In this sense, it is natural to have higher welfare states than the social optimal one.

If the budget of the government for intervention is strictly closed, numerical results for this budget viable intervention are given in Table 5-4.

Table 5-4 Numerical results of insurance equilibrium under budget-viable intervention

e_2	$X^*(\mathbf{g})$	$n^*(\mathbf{g})$	ν	m_1	m_2	$\overline{p}$	$v_i(0)$	$v_i(1)$	$\mathrm{E}W_i$
30	17.321	0.272	0.683	53.447	20.015	6.36	14.79	6.86	2.310
40	20.000	0.267	0.674	70.945	25.879	7.26	18.62	9.02	2.562
50	22.361	0.264	0.668	88.454	31.685	8.06	22.23	11.06	2.752
60	24.495	0.261	0.663	105.970	37.449	8.78	25.66	13.03	2.906
70	26.458	0.259	0.660	123.491	43.179	9.45	28.97	14.92	3.035

So the intervention exactly diminishes cross-state price difference. At the instance that the government finishes the intervention, all risks are shifted back to the rural producers and urban workers become risk-free. After fulfilling the crop disaster insurance contract, they are borne to the risk at the same level. With the free-migration or labor-allocation assumption, finally rural producers and urban workers share the same level of welfare state in each collective state.

Economic efficiency in allocating resources and risk

The efficiency of the economy is measured by three piece of information, two regarding resources allocation within each time period, X and n, and one regarding resources allocation across time periods, $\mathbf{g}$.

The benchmark case in which the price in the goods market plays the role of resources allocation performs at the lowest economic efficiency. Per capita output level is relatively small while too much labor is allocated to farming. It shows the negative externality induced by the subsistence constraint. In order to avoid suffering from high food price, laborers more than the optimal are working in the rural sector. In the aggregate manner, grain output is too much compared to the social optimum.

The insurance equilibrium under optimal intervention strategy exactly leads to social optimum in terms of economic efficiency. Government intervention plays the role of diversifying disaster risk to the time dimension while the crop disaster insurance market re-allocates the residual risk within each period/ state. The intervention strategy, however, is not budget-viable because it requires the government to hold extra monetary resources. The government will be in debt in terms of urban goods if the intervention strategy is carried out. With the budget-viable intervention, the crop disaster insurance market reaches to some sub-optimal equilibrium. Rural producers are exactly producing at the social optimal per capita output level but there are too little labor allocated to the rural sector. In this sense, beyond the intervention in the form of grain reserve policy, government policies must create incentives to attract more laborers to work in the rural sector.

5.7 IMPROVING THE INSURANCE MARKET EQUILIBRIUM

Now suppose a government does choose the budget-viable intervention strategy that exactly smoothes state-contingent prices. The question is what kind of further intervention can be carried out so that the economic efficiency of insurance equilibrium can be improved. We call government intervention that is used to modify the insurance equilibrium under budget-viable grain policy the "patch intervention". The purpose of the patch intervention is to increase the number of laborers allocated to the rural sector to move closer to the social optimum.

Lump-sum transfer

The first-best choice of the patch intervention is, of course, the most powerful and common intervention strategy, lump-sum transfer. Through direct monetary transfer (the urban goods in this model) from urban workers to rural producers, number of laborers in the urban sector can be controlled without inducing any externalities on rural producers' decision-making on per capita output level. If the lump-sum tax/subsidy to individual of group *i* is denoted by τ_i , budget constraints of individuals change to

$$\begin{aligned} e_1(t) &= \overline{p} \cdot \left(\delta(t) X - \overline{x}\right) - C(X) + (t-\nu) m_1 + \tau_1 \\ e_2(t) &= w_2 - \overline{px} - (t-\nu) m_1 + \tau_2 \end{aligned}, \text{ for both } t \tag{5.54}$$

It is assumed that lump-sum transfer is completed independent of the collective state of the world. Budget constraint of the patch intervention must follow

$$n\tau_1 + (1-n)\tau_2 = 0 \tag{5.55}$$

The right patch intervention is then to let the equilibrium population distribution pattern identical to the social optimal one. In this sense, the crop disaster insurance market under government intervention policies derives some second-best equilibrium of this dual-economy. Intra-period allocation of resources for production exactly coincides with the social optimal choice. Inter-period diversification of disaster risk is sub-optimal because of the budget constraint of non-arbitrage transaction.

Direct subsidy to crop insurance premium

Another intervention strategy that has been intensively discussed is direct subsidy to crop insurance premium. It can be formulated in the way below:

$$\begin{aligned} e_1(t) &= \overline{p} \cdot \left(\delta(t) X - \overline{x}\right) - C(X) + (t-(\nu-\sigma)) m_1 - \tau \\ e_2(t) &= w_2 - \overline{px} - (t-\nu) m_1 - \tau \end{aligned}, \text{ for } t = 0, 1, \tag{5.56}$$

such that each individual is imposed a uniform lump-sum tax τ . This amount of fiscal resources is then used to give subsidy to the premium paid by rural producers. In this sense, the effective premium rate faced by rural producers is $\nu-\sigma$ while the nominal premium rate at which urban workers are collecting premium revenue is still ν. Of course, the premium subsidy can put in a proportional way, e.g. $\nu(1-\rho)$ with ρ denoting the subsidy rate. The budget constraint of the government for this patch intervention is

$$\sigma n m_1 = \tau \tag{5.57}$$

The discussion regarding this patch strategy is whether it can lead to the second-best equilibrium derived by the lump-sum transfer patch intervention. As discussed in Chapter 4, premium subsidy does create incentive attract more individuals to work in the rural sector. When it is carried out at relatively low rate, however, per capita output at individual level simultaneously drops. Now we have to check whether the result still applies in this model. When it reaches to equilibrium in the insurance market, per capita output level is determined by (5.41). Update to the current intervention strategies,

$$(1-(\nu-\sigma))\,\overline{p}\delta(0)+(\nu-\sigma)\,\overline{p}\delta(1)-C'(X)=0 \tag{5.58}$$

Our interest is the impact of σ on individuals' optimal output level, X. Define

$$\frac{\partial f(X(\sigma),\sigma)}{\partial X}=(1-(\nu-\sigma))\,\overline{p}\delta(0)+(\nu-\sigma)\,\overline{p}\delta(1)-C'(X)$$

which equals 0 at the optimal output level. It follows that

$$\frac{\partial^2 f(X,\sigma)}{\partial X\partial\sigma}=\left[\delta(0)-\delta(1)\right]\overline{p}+\left[(1-(\nu-\sigma))\,\delta(0)+(\nu-\sigma)\,\delta(1)\right]\frac{\partial\overline{p}}{\partial n}\frac{\partial n}{\partial\sigma}$$

From equation (5.51) we know that $\partial n/\partial\sigma=0$. According to envelop theorem, it strictly follows

$$\operatorname{sign}\frac{dX(\sigma)}{d\sigma}=\operatorname{sign}\frac{\partial^2 f(X,\sigma)}{\partial X\partial\sigma}>0 \tag{5.59}$$

It implies that heavier subsidy induces higher output level, which is not consistent with the result in Chapter 4. So what is the reason for this inconsistency? The answer is government grain policy. Let us recall the critical equation regarding the same issue in Chapter 4:

$$\operatorname{sign}\frac{dX(\sigma)}{d\sigma}=\operatorname{sign}\left[p(0)\,\delta(0)-p(1)\,\delta(1)\right]$$

In chapter 4, it strictly holds that $\sum_t p(t)\,\delta(t)<0$ and consequently lowering effective premium rate leads to lower per capita output level when the insurance coverage is partial. In this model, when there is no government grain policy, the result still holds, as

$$p(t)\,\delta(t)=\frac{\alpha}{1-\alpha}\frac{Y\delta(t)}{n\delta(t)\,X-\overline{x}}=\frac{\alpha}{1-\alpha}\frac{Y}{nX}\left[1+\frac{\overline{x}}{n\delta(t)\,X-\overline{x}}\right]$$

$$\frac{d\left[p(t)\,\delta(t)\right]}{d\delta(t)}<0$$

Therefore, it is the government intervention that changes the state-contingent price vector and induces this inconsistency. After government intervention it follows that $\sum_t p(t)\delta(t) > 0$ and therefore premium subsidy encourages per capita output. This finding coupling the one we get in Chapter 4, gives clear answer to the controversial question that is raised at the beginning of chapter 4. It depends on the relationship between state-contingent labor income or revenue of producing grains whether direct subsidy to insurance premium can lead to higher per capita output level. If no government intervention that changes the cross-state income patterns is carried out, the answer is negative.

The last issue in this section is whether the premium subsidy system can ever lead to the second-best equilibrium. The answer is NO. In the social optimum, optimal allocation and redistribution behaviors are decided independently. The second-best equilibrium is identical to the social optimum except its imperfect inter-temporal diversification. With the premium-subsidy patch intervention, the level of inter-temporal diversification is the same as the second-best equilibrium, but it can only guarantee either one out of two criteria for intra-temporal allocation of resources for production. So in the context of the current model, we still insist that direct subsidy to premium rate is not a good choice for the patch intervention. Distorting intervention, irrespective of encouraging or discouraging per capita output level, is not suggested.

5.8 SUMMARY

The main purpose of this chapter is to explain the difference between the result of the model in Chapter 4 and what people have learned from reality. It has successfully explained the difference with government grain policy that tries to diminish cross-state (period) variance of grain supplies and market prices. The implication from the social optimum is very explicit: perfect inter-temporal diversification of disaster risk attached to production is the first-best choice for an economy. Another important finding from the model is the redistribution effect of grain reserve policy. When state-contingent prices change, state-contingent *ex post* welfare states of individuals will change correspondingly. Consequently, risk-bearing of individuals is re-allocated within each time period (state).

Government intervention in the form of full-cover social insurance system to the grain market can also derive the social optimum. In that sense, domestic crop disaster insurance is unnecessary. If the government adopts intervention following the non-arbitrage transaction principle, domestic crop insurance market is then expected to re-allocate the risk between sectors after the risk is diversified to the time dimension with the intervention policy. The optimal intervention strategy is to stabilize the aggregate market supply of grains. It is important to notice that the government had better not use the stabilization of state-contingent prices as the criteria of perfect inter-temporal diversification of the risk. Their equivalency largely depends on the specific intervention strategy that the government uses and what kind of budget constraint it follows. For instance, in our model when the government follows the optimal intervention strategy, the price in the lucky state will be larger than the one in the unlucky state. If the government intervention strictly follows both its substantial constraint and monetary constraint under non-arbitrage transaction, it exactly reserves the market price of grain but the risk is only partially diversified inter-temporally. When the government follows its budget viable intervention under non-arbitrage transaction, monetary transfer from tax-payers to rural producers will be necessary to increase economic efficiency in allocating resources and risk. The transfer had better be in the lump-sum form rather than premium subsidy to crop insurance, as the later one misses between per capita output level and allocation of labor.

The essential difference between the full cover social insurance system and the non-arbitrate-operation intervention is that the former approach is neutral to the market approach. Under the full-cover social insurance system, the price of grains follows strictly by the market mechanism which is still determined by both social aggregate urban goods available for consumption and social aggregate grains available for consumption. Under the none-arbitrate-operation intervention, although the price is still determined by the market, the market signal is distorted by government intervention. In this sense, stabilizing state-contingent price and perfect inter-temporal diversification diverge.

In the model, in order to keep our focus on inter-sectoral issues, the details about inter-temporal approach are reduced to the minimal level. This part of discussion will be further elaborated in the coming Chapter 6.

Chapter 6

Life-time Constraint, Disaster Reserve, and Inter-temporal Diversification of Disaster Risk

6.1 OUTLINE OF THIS CHAPTER

The model presented in Chapter 5 has touched upon the inter-temporal aspect of disaster risk diversification in the simplest manner. The strong assumption that grains kept in the reserve are non-perishable is quite unrealistic. Due to the focus of that model, the discussion has been forced to be limited with respect to the inter-temporal issue.

This chapter presents a supplementary model on the inter-temporal issues with more focused and generalized structure. The main purpose is to model the dynamic changes of disaster reserve and the role of disaster reserve in inter-temporal and international diversification of disaster risk. Technically, the model in this chapter provides a method in determining optimal portfolio management of a disaster reserve and provides optimal risk financing by combining international (inter-regional) and inter-generational approaches. Practically, this extended model is intended to provide some implications for policy-makers from the countries where domestic insurance markets are emerging while international insurance contracts are too expensive to afford. A catastrophic reserve can be of multiple uses for those less-developed but highly disaster-prone countries. It can be implemented as a public disaster insurance system with low coverage level but fair premium rate. Alternatively, it can be a premium subsidy system attached to existing private insurance programs. Last but not least, it is also important when there has existed a sound primary insurance system in need of reinsurance coverage.

In order to keep the discussion condensed and generalized, this chapter adopts a two-country structure with one homogeneous commodity produced only for private consumption. Production behavior is described with the minimal detail. The model upgrades to a dynamic one by following the classical structure of two-period overlapping generations. Disaster-damage-prone individuals have two alternatives to finance their risks: the one is to purchase international insurance coverage while the other is to join the inter-generational diversification program operated by their government. The model then shows how a disaster reserve can be set up by a government, how the relationship between tax and subsidy is determined dynamically, and how the government can increase the capacity of the reserve by making international loans.

The structure of this chapter is organized as follows. In section 6.2, model assumptions of "one-good, two-country and two-period overlapping generations structure" is explained in details. Section 6.3 introduces three basic cases of the model. In the benchmark case (section 6.3), disaster-damage-prone individuals have no means to finance their risks. Next to the benchmark case, section 6.4 gives the equilibrium in which individuals from the disaster-damage-free country offer international insurance to the prone individuals. Section 6.5 describes the dynamic funding process of a disaster reserve and proves its equivalency to fair insurance system when capacity constraint is relaxed. Then individuals' welfare states are compared across three cases. Section 6.6 discusses the viability and equilibrium behavior of individuals when both international insurance which transfers the risk between countries and domestic disaster reserve which pools the risk along the time are available. Section 6.7 summarizes this chapter and put related discussions.

6.2 MODEL ASSUMPTIONS

The model is based on a one-good, two-country, and two-period overlapping generations structure. Assume a small economy with two countries, one developed country (DC) and one less developed country (LDC). This scenario may well be interpreted as two groups of countries, or one country and the rest of the world. This setting is quite similar to the previous models that it has two geographical regions. The difference is that when two-country is assumed rather than two-region, there is neither a central government nor a wise central planner. In both countries there is only one sector, producing a homogeneous goods used for private consumption of individuals.

The essentail strucutre of this model is the two-period overlapping generations structure with respect to population. This framework has been adopted because the main purpose of the study is to show the constraint in people's life time that substantially reduces the capacity of inter-termporal diversification of disaster risk at the individual level. Economists have developed two types of simple but extreme frameworks to model the lifetime saving and consumption behavior of individuals: the Ramsey structure and the overlapping generations structure. The Ramsey model assumes that each individual lives in an infinite time horizon and his saving/ consumption behavior is modeled in a continuous manner. In the overlapping generations model, individuals live for only several (generally two) discrete periods. The advantage of overlapping generations is that individuals will face strong restriction in making loans: if they are in the final period of their lifetime, they will have no credit to obtain any loans. This implies the indispensible role of the government in the intergenerational diversification of risk. If the Ramsey framework is assumed, the problem will not occur and discussion converges to Yaari's work (Yaari, 1976).

The two-period overlapping generations framework indicates that an individual's lifetime is arbitrarily divided into two periods, the young and the old. At any arbitrary period t, there are two generations alive. For instance, in Fig. 6-1, each segment with two black dots at both ends is used to denote one period in an individual's lifetime, and the individual has in total two periods throughout the lifetime. At time period 4, generation 3 will be at the later period of lifetime while generation 4 is at the first period of lifetime. Therefore, at time period 4, generation 3 and generation 4 are living together. In this period, we call generation 3 "the old generation" while generation 4 "the young generation". The population grows at some rate along the time. In this model, for the sake of simplicity, the growth rate is assumed to be 0 and consequently the population is static. The model further normalizes the population to 2, with half of that in each country. At any time t, there are only one young person and one old person in each country.

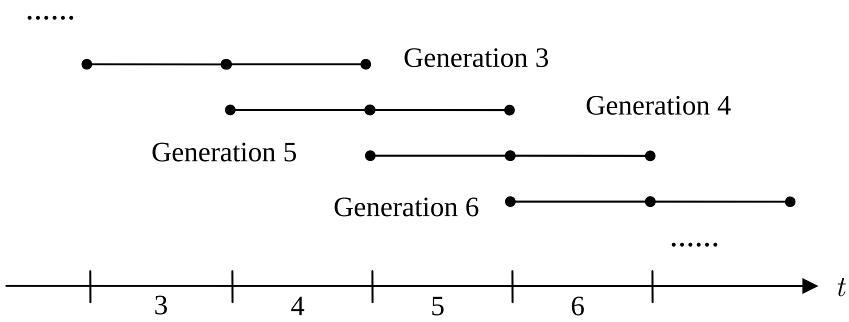


Fig. 6-1 Illustration of the two-period overlapping generations structure

Individuals work only in the first period of lifetime, e.g., some period t, while they consume only in the later period of lifetime, period $t+1$. They supply inelastically one unit of labor and earn a wage of w_t. This wage is saved, which generates the capital stock K_{t+1}^i for production of the next period in country *i*, with the input of labor from the next generation. The production follows technology of $F(K,N)$ showing constant-return-to-scale. It can be re-put as a function of capital-labor ratio, $f(k)$, satisfying the Inada conditions, $f' > 0 > f''$. Firms and individuals are assumed to be price-takers. After the production process has finished, people of the elder generation get return from their capital investment (savings) and is entirely used for consumption, c_{t+1}^i. Each individual's welfare is then measured by a utility function of consumption, $u(c)$, which is strictly concave, $u' > 0 > u''$.

The small world in the model is exposed to disaster risks. Similar to previous chapters, it is defined that there are two collective states of nature in this small world, the lucky and the unlucky with probability of $\pi(0)$ and $\pi(1)$, respectively. Only the capital stock for production is going to be damaged by disasters. As for the ratio of damage, it is presumed that the DC is much more damage-resistant to disasters than the LDC by assuming the DC has well-developed disaster mitigation infrastructures and a well-functioning domestic risk diversification system. Thus, the damage ratio is arbitrarily set as 0. The capital investment of the LDC will be damaged at the ratio of $(1-\delta(1))$.

As discussed in previous models, openness between regions is of vital importance with respect to risk and resources allocation. In this model the international labor market is set as closed which means that migration is not possible. The international capital market is unilaterally open and there is no transaction costs for DC individuals to invest in the LDC. If the capital market is absolutely closed, the result would be trivial and unrealistic. If the capital market is completely open and frictionless, the two-country-setting of the model does not make sense as individuals becomes free to invest in both countries. The international capital market will then play the role of transferring disaster risk, and it will completely take the place of the international insurance market. The unilateral setting may corresponding to the case in reality that developed countries are investing a lot in developing countries. Generally it is because when individuals in a LDC try invest in a foreign DC, they will face many challeneges in various aspects, e.g. less developed security exchanges, insufficient knowledge on transactions of financial commodities, or having few international firms.

The unilateral openness of capital market allows DC individuals to invest in the LDC and take a part of risk, in case that the rate of return of the risky investment is higher than risk-free domestic investment. The implicit assumption behind is that since the LDC is less developed and sometimes struck by disasters, the total amount of capital stock for production is always less than that in the DC and generates higher risk-adjusted rate of return. This risk-taking behavior changes the risk-free status of DC individuals and their capacity of absorbing risk decreases.

The essential discussion of the model is the optimal disaster risk diversification strategy of the LDC individuals. Two types of financial instruments are provided for them to do so, the one is the international disaster insurance contract offered by the insurance company of the DC, while the other is domestic intergenerational risk financing system operated by the LDC government.

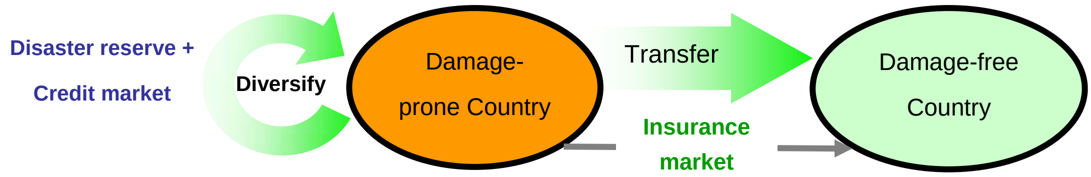


Fig. 6-2 Approaches for disaster risk transfer and diversification

6.3 THE BENCHMARK CASE

The LDC's economy

A LDC individual of generation t earns a wage of w_t^1 and saves it in domestic banks, which is the only option for this individual in the benchmark case,

$$s_{1,t}^1 = w_t^1 \tag{6.1}$$

Then accumulated capital stock for production in the LDC equals

$$k_{t+1}^{1,j} = \delta(j)\left(s_{1,t}^{1} + s_{1,t}^{2}\right), \text{ for } j=0,\ 1, \tag{6.2}$$

in which $s_{1,t}^{2}$ is the capital investment (saving) from DC individuals. j is used here to denote the state of the world. When $j = 0$, it refers to the Lucky state and $\delta(0) = 1$ implies no damage to capital investment. When $j = 1$, it implies that some disaster(s) happen in this period and capital investment will be damaged at the rate of $(1 - \delta(1))$. After production is finished, generation t gets payment for the investment,

$$\begin{aligned} c_{t+1}^{1,j} &= r_{t+1}^{1,j} \cdot \delta(j) \cdot s_{1,t}^{1} \\ r_{t+1}^{1,j} &= f'\left(k_{t+1}^{1,j}\right) \end{aligned}, \text{ for } j=0,\ 1 \tag{6.3}$$

Generation $t+1$, the younger people who contribute labor to the production, get wage

$$w_{t+1}^{1,j} = f\left(k_{t+1}^{1,j}\right) - r_{t+1}^{1,j} \cdot k_{t+1}^{1,j}, \text{ for } j=0,\ 1, \tag{6.4}$$

which is then again saved in domestic banks for capital investment of period $t+2$.

The DC's economy and individuals' optimal investment behavior

Capital stock for production in the DC comes only from the savings of domestic individuals,

$$k_{t+1}^{2} = s_{2,t}^{2} \tag{6.5}$$

which determines risk-free interest rate and labor wage rate in the DC

$$\begin{aligned} r_{t+1}^{2} &= f'\left(k_{t+1}^{2}\right) \\ w_{t+1}^{2} &= f\left(k_{t+1}^{2}\right) - r_{t+1}^{2} \cdot k_{t+1}^{2} \end{aligned} \tag{6.6}$$

The investment behavior of a DC individual is then described by the following optimization problem:

$$\max_{s_{1,t}^{2}, s_{2,t}^{2}} \mathrm{E}\, U^{2} = \pi(0)\, u\left(c_{t+1}^{2,0}\right) + \pi(1)\, u\left(c_{t+1}^{2,1}\right)$$

such that

$$\begin{aligned} w_{t}^{2} &= s_{1,t}^{2} + s_{2,t}^{2} \\ c_{t+1}^{2,j} &= \left(1 + r_{t+1}^{1,j}\right) \cdot \delta(j) \cdot s_{1,t}^{2} + \left(1 + r_{t+1}^{2}\right) s_{2,t}^{2} \end{aligned}, \text{ for } j=0,\ 1 \tag{6.7}$$

Let $R_{t+1}^{1,j} = \left(1 + r_{t+1}^{1,j}\right) \cdot \delta(j)$ and $R_{t+1}^{2} = \left(1 + r_{t+1}^{2}\right)$ denote the gross rate of return. The first-order condition for maximization is

$$\pi(0)\,u'\left(c_{t+1}^{2,0}\right)\left(R_{t+1}^{1,0}-R_{t+1}^{2}\right)+\pi(1)\,u'\left(c_{t+1}^{2,1}\right)\left(R_{t+1}^{1,1}-R_{t+1}^{2}\right)=0\,, \tag{6.8}$$

yielding optimal investment behavior $s_{1,t}^{2*}=s_{1,t}^{2}(w_t^2), s_{2,t}^{2*}=s_{2,t}^{2}(w_t^2)$.

If we specify the production function as $f(k)=\ln k$ and instant utility function following CRRA preference of degree one, $u(c)=\ln c$, and assume $\pi(1)=0.2$, $\delta(1)=0.5$, numerical examples can be derived as in Table 6-1.

Table 6-1 Numerical results of the benchmark case

Example *No.*	w_1^t	w_2^t	$s_{1,t}^{2*}$	$s_{2,t}^{2*}$	R_{t+1}^{2}	$R_{t+1}^{1,0}$	$R_{t+1}^{1,1}$	$\mathrm{E}\,U^{1*}$	$\mathrm{E}\,U^{2*}$
1	5	5	0.00	5.00	1.200	1.200	0.400	1.684	1.792
2	5	10	0.00	10.00	1.100	1.200	0.400	1.684	2.398
3	5	15	0.80	14.20	1.070	1.172	0.372	1.657	2.776
4	5	20	1.39	18.61	1.054	1.156	0.356	1.642	3.048
5	5	25	1.85	23.15	1.043	1.146	0.346	1.631	3.261
6	6	15	0.00	15.00	1.067	1.167	0.367	1.834	2.773
7	6	20	0.56	19.44	1.051	1.153	0.353	1.820	3.046
8	6	25	0.98	24.02	1.042	1.143	0.343	1.811	3.260
9	6	30	1.32	28.68	1.035	1.137	0.337	1.804	3.436
10	6	35	1.59	33.41	1.030	1.132	0.332	1.799	3.585

Intuitively, DC individuals invest to the LDC only when the domestic gross rate of return on capital investment R_{t+1}^{2} lies between the gross rates of return of investing in the LDC of two states. The investment of DC individuals actually forms negative effect on the expected utility of LDC elder generation. In the LDC, domestic investors are harmed because more abundant total investment lowers the expected rate of return. But abundant foreign investment will increase the domestic wage rate of the younger generation. In this sense, it is not absolutely a bad thing for the LDC. DC investors, of course, improve their income as well as expected utility by taking the risk.

6.4 RISK TRANSFER VIA INTERNATIONAL INSURANCE MARKET

In the benchmark case, LDC individuals have no means to manage their risks. In this sense, international disaster insurance offered by DC individuals is viable. If we use ν and m^i to denote insurance premium rate and coverage, the investment behavior for a LDC individual is:

$$\max_{s_{1,t}^1, m_t^1} \mathrm{E}\,U^1=\pi(0)\,u\left(c_{t+1}^{1,0}\right)+\pi(1)\,u\left(c_{t+1}^{1,1}\right)$$

such that

$$\begin{aligned} w_t^1 &= s_{1,t}^1+\nu m_t^1 \\ c_{t+1}^{1,j} &= R_{t+1}^{1,j}s_{1,t}^1+j\cdot m_t^1 \end{aligned}, \text{ for } j=0,\,1 \tag{6.9}$$

Still, *j* is used to denote the state of the world. When $j = 0$ and no disasters happen, the indemnity $j \cdot m_t^1$ is 0 and therefore no compensation is transferred to policyholders. When $j = 1$, policyholders will exactly get indemnity equals to his insurance coverage, m_t^1. The first-order condition for maximization is

$$\frac{u'\left(c_{t+1}^{1,0}\right)}{u'\left(c_{t+1}^{1,1}\right)} = \frac{\pi(1)}{\pi(0)} \frac{1-\nu R_{t+1}^{1,1}}{\nu R_{t+1}^{1,0}}, \tag{6.10}$$

which yields the optimal demand behavior $m_t^{1*} = m_t^1(\nu)$.

On the other hand, investment behavior for a DC individual changes to

$$\max_{s_{1,t}^2, s_{2,t}^2, m_t^2} \mathrm{E}\, U^2 = \pi(0)\, u\left(c_{t+1}^{2,0}\right) + \pi(1)\, u\left(c_{t+1}^{2,1}\right)$$

Such that
$$\begin{aligned} w_t^2 &= s_{1,t}^2 + s_{2,t}^2 - \nu m_t^2 \\ c_{t+1}^{2,j} &= R_{t+1}^{1,j} \cdot s_{1,t}^2 + R_{t+1}^2 s_{2,t}^2 - j \cdot m_t^2 \end{aligned}, \text{ for } j=0, 1 \tag{6.11}$$

First-order conditions for maximization are similar to the previous one,

$$\frac{u'\left(c_{t+1}^{2,0}\right)}{u'\left(c_{t+1}^{2,1}\right)} = \frac{\pi(1)}{\pi(0)} \frac{1-\nu R_{t+1}^{1,1}}{\nu R_{t+1}^{1,0}} = \frac{\pi(1)}{\pi(0)} \frac{1-\nu R_{t+1}^{2}}{\nu R_{t+1}^{2}}, \tag{6.12}$$

while yield optimal insurance supply curve $m_t^{2*} = m_t^2(\nu)$. The equilibrium in time period t is finally determined by clearing the international insurance market

$$m_t^1(\nu) = m_t^2(\nu) = m_t^* \tag{6.13}$$

If we give the same specification as in the previous section, the following numerical results can be derived:

Table 6-2 Numerical results of transferring disaster risk via international insurance market

Example *No.*	w_1^t	w_2^t	$s_{1,t}^{1*}$	ν	m_t^*	$s_{1,t}^{2*}$	$s_{2,t}^{2*}$	R_{t+1}^2	$R_{t+1}^{1,0}$	$R_{t+1}^{1,1}$	$\mathrm{E}\,U^{1*}$	$\mathrm{E}\,U^{2*}$
1	5	5	4.69	0.207	1.480	0.00	5.31	1.188	1.213	0.713	1.706	1.788
2	5	10	4.68	0.205	1.548	0.07	10.24	1.098	1.210	0.710	1.704	2.398
3	5	15	4.66	0.208	1.637	0.88	14.46	1.069	1.180	0.680	1.678	2.776
4	5	20	4.64	0.209	1.708	1.49	18.87	1.053	1.163	0.663	1.662	3.049
5	5	25	4.63	0.209	1.766	1.96	23.41	1.043	1.152	0.652	1.652	3.262
6	6	15	5.59	0.208	1.983	0.09	15.32	1.065	1.176	0.676	1.856	2.773
7	6	20	5.57	0.209	2.065	0.67	19.76	1.051	1.160	0.660	1.842	3.046
8	6	25	5.55	0.209	2.132	1.12	24.33	1.041	1.150	0.650	1.833	3.260
9	6	30	5.54	0.209	2.187	1.47	28.99	1.034	1.143	0.643	1.827	3.436
10	6	35	5.53	0.208	2.233	1.77	33.70	1.030	1.137	0.637	1.822	3.585

Comparing to the benchmark case (Table 6-1), the expected utility of the LDC individual improves significantly while the welfare state of the DC individual increases slightly. The existence of international insurance contract does realize mutual advantage and Pareto improvement. In this set of equilibria, the premium rate of international disaster insurance is higher than the fair one, as insurers, DC individuals in this model, are not risk neutral any longer since they are taking the risk via the international capital market.

6.5 INTER-GENERATIONAL DISASTER RISK DIVERSIFICATION

Besides the international approach for risk transfer in the previous section, it is also possible to diversify disaster risk along the time, as stated in the literature review in Chapter 2. The government of the LDC is able to "smooth" the consumption among generations with the "buffer-stock" strategy by setting up a disaster reserve (DR) and making international loans. If the subject discount rate of the government is θ, the objective function of the government is

$$W = \sum_t (1+\theta)^{-t} \mathrm{E}\, U^1$$

If the time horizon is long enough and each generation's life time is relatively short, the social welfare function can be approximated to a continuous one:

$$W = \int_0^\infty \mathrm{E}\, U^1 e^{-\theta t} dt$$

Assuming that the economy is in steady state where each generation behaves in identical economic environment in *ex ante* sense, the objective function that the government maximizes can be reduced to the expected utility function of the representative generation. Thus, the social welfare maximization problem is equivalent to the personal optimization problem of the representative individual.

The "buffer-stock" strategy for inter-temporal risk diversification is shown in Fig. 6-3. In order to diversify disaster risk among generations, the government will have to firstly set up a disaster reserve which collects tax revenues from citizens, which is kept either in national bank or trust fund provided by international financial service. When some disaster hits, the liquid capital will be used to subsidize victims. If the capital in the reserve is contingently in short, the government will have to make loans from international financial institutions or foreign countries, or get post disaster donors' grant to fill the resources gap. After the disaster, tax revenues will be used to repay the loan on the one hand and accumulate fund in the disaster reserve on the other. The reserve would perfectly smooth the consumption across generations if the ratio of tax to subsidy is appropriately given, and if the government does not face any constraints in making international loans.

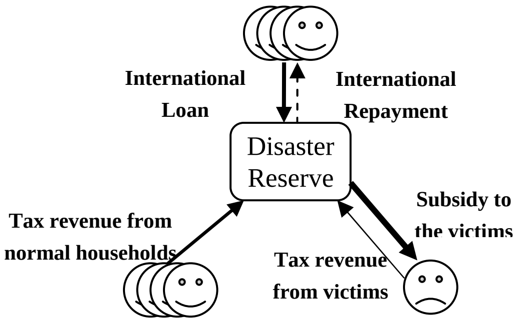


Fig. 6-3 Buffer-stock strategy for inter-temporal diversification of disaster risk

The DR is the major component of the instrument and the cash flows include tax revenues, subsidies, international loans and repayments. In this simple model we do not consider the portfolio management problem of the disaster reserve but simply assume that this amount of money is invested in the DC so that it will not be damaged by disasters. The funding process of the disaster reserve can be formulated as the stochastic process below:

$$dZ_t = r_{t+1}^{2*} Z_t dt + \tau dt - \eta dt - (\sigma - \zeta) dN(t) \tag{6.14}$$

in which Z_t is the capital kept in the DR, raised by the LDC's government for diversifying disaster risk, τ is the annual tax imposed on LDC agents to accumulate capital, and η is the mean annual repayment from the DR to the lender(s). The subsidy σ consists of two parts: $\sigma - \zeta$ from the DR and ζ from the international loan. International loan is embodied in the subsidy because the accumulation of DR could be very slow and it is likely not enough to cover the damage of a catastrophic disaster, especially if a disaster occurs shortly after the reserve is created (Kunreuther and Linnerooth-Bayer, 2003). Therefore international loans are useful to cushion large random shocks which exceed the capacity of the DR. Once a part of the subsidy comes from foreign loans, the following generations will have to pay back the loan, which means that the annual repayment $\eta > 0$. $dN(t)$ is a standard Poisson process denoting the arrival of natural disasters. The property of the Poisson process implies that $dN(t) \sim \lambda dt$, which means that the expected occurrence of a disaster in one unit time is equal to the intensity of the process, and equals the probability of the event, $\lambda = \pi(1)$ in this model.

In this two-country and overlapping-generation model, direct loans between individuals are not possible because victims who are in need of disaster aid cannot repay their loans as they have already been in the latter period of their lifetime. Therefore, the LDC government must enact the representative of its citizens to make loans. This structure makes essential difference from models discussing the inter-temporal aspect of risk diversification.

The process of the repayment is complicated, because the loan should be repaid within the lifetime of the DC agents. In order to illustrate the process (Fig. 6-4), suppose in period 1 the government borrowed ζ from the DC young generation $G(y,1)$, and this loan is to be fully repaid in the period $T+1$. Of course, T should be larger than ζ/τ, since annual repayment cannot exceed the annual repayment capacity of the LDC. In general conditions, the present value of annual average repayment is simply ζ/T. As all individuals live only for two periods in this model, the loan must be fully repaid within the DC individuals' lifetime. The LDC government will have to borrow again at time 2 from the foreign young $G(y,2)$ and repay the money to the foreign old $G(o,2)$. The present value of the new loan from $G(y,2)$ would then be $\zeta(T-1)/T$. The government then has to repeatedly borrow from the foreign young generation and use the loan plus domestic tax revenue to repay the existing loan to the foreign old generation, until all loans are completely repaid. The essence of this case and the general case are the same: both the present values of actual mean annual repayment are $\eta=\zeta/T$, but processes are different.

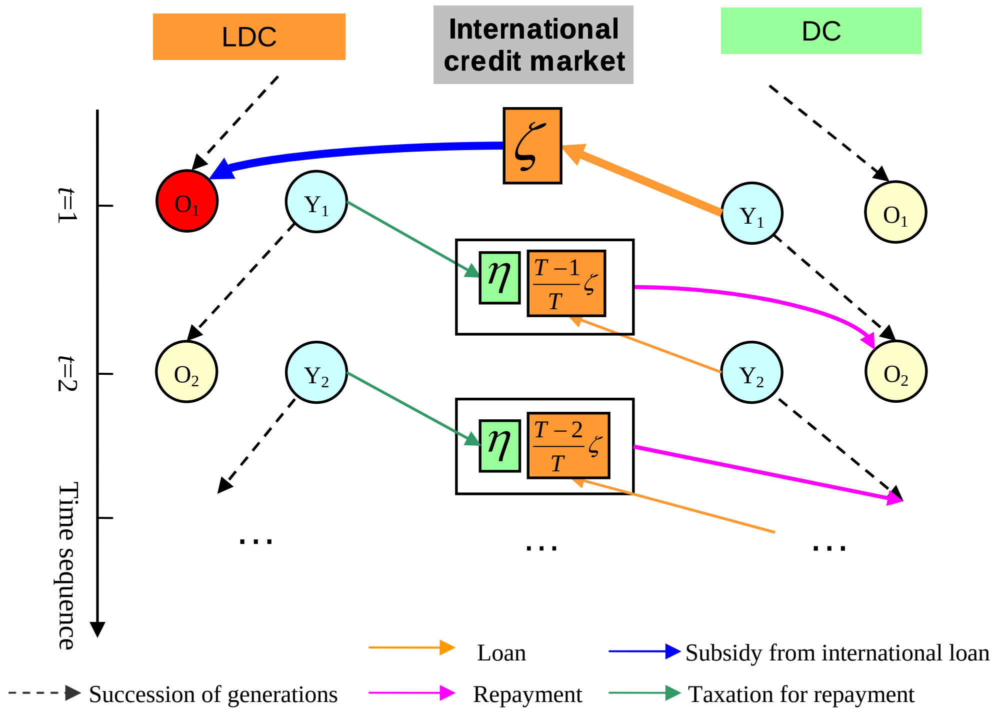


Fig. 6-4 Financing process of the international loan

The dynamic funding process of the international loan can be formulated as the stochastic process:

$$dL_t = \gamma^* L_t dt + \eta dt - \zeta dN(t) \tag{6.15}$$

Note that here γ is used instead of r_{t+1}^{2*} for the sake of simplicity. Solving for $\mathrm{E}Z_t$ and $\mathrm{E}L_t$ (for details, please refer to Appendix III),

$$\begin{aligned} \mathrm{E}Z_t &= \left(\frac{\tau-\eta-(\sigma-\zeta)\pi(1)}{r}\left(1-e^{-\gamma t}\right)+Z_0\right)e^{\gamma t} \\ \mathrm{E}L_t &= \left(\frac{\eta-\zeta\pi(1)}{r}\left(1-e^{-\gamma t}\right)+L_0\right)e^{\gamma t} \end{aligned} \tag{6.16}$$

By No-Ponzi-Game condition (Blanchard and Fischer, 1989), the sustainability constraints of the disaster reserve fund and the balancing condition of the international loan are

$$\lim_{t\to\infty} \mathrm{E}Z_t e^{-\gamma t} = 0 \text{ and } \lim_{t\to\infty} \mathrm{E}L_t e^{-\gamma t} = 0$$

Hence, the sustainability constraints of disaster reserve and balancing condition for international loan change to

$$\frac{\tau - \eta - (\sigma - \zeta)\pi(1)}{\gamma} + Z_0 = \frac{\eta - \zeta\pi(1)}{\gamma} + L_0 = 0 \tag{6.17}$$

By letting the initial amount of disaster reserve and loan both equal to 0, we get the equilibrium condition in disaster reserve and international loan

$$\eta/\zeta = \pi(1) \text{ and } \tau/\sigma = \pi(1), \tag{6.18}$$

which implies that the ratio between tax paid to government and the subsidy is equal to the probability of disaster. In perfect conditions that no restriction is put on international loans, the disaster reserve enacts a risk neutral financing resources and absorbs all disaster risk from domestic individuals, diversifying it along the time perfectly. It is equivalent to an insurance system offering fair premium rate.

The social optimization problem for the government of the LDC, focusing on the representative generation, is

$$\max_{s_{1,t}^1, \tau_t} \mathrm{E}\,U^1 = \pi(0)\,u\left(c_{t+1}^{1,0}\right) + \pi(1)\,u\left(c_{t+1}^{1,1}\right)$$

such that
$$\begin{aligned} w_t^1 &= s_{1,t}^1 + \tau_t \\ c_{t+1}^{1,j} &= R_{t+1}^{1,j} s_{1,t}^1 + j\cdot\sigma_t\left(\tau_t\right) \end{aligned}, \text{ for } j = 0, 1 \tag{6.19}$$

On the other hand, the budget constraint of the DC individuals change to

$$\begin{aligned} w_t^2 &= s_{1,t}^2 + s_{2,t}^2 + \zeta \\ c_{t+1}^{2,j} &= R_{t+1}^{1,j}\cdot s_{1,t}^2 + R_{t+1}^2\cdot\left(s_{2,t}^2 + \zeta\right) \end{aligned}, \text{ for } j=0, 1 \tag{6.20}$$

It also implies that the capital kept in the disaster reserve is invested to the DC so that it is risk-free:

$$k_{t+1}^2 = s_{2,t}^2 + Z_t \tag{6.21}$$

In (6.20), there are three investment options for the DC individual: a) invest to the LDC; b) invest domestically; and c) lend money to the LDC government for dynamic funding of the disaster reserve. The optimal investment choice of the DC individual can be denoted as $\left(s_{1,t}^{2*}, s_{2,t}^{2*}, \zeta\right)$. Actually $s_{2,t}^{2*}$ and ζ are equivalent because they yield the same rate of return. In this sense, a DC individual of generation $t+1$ is willing to lend maximally $s_{2,t+1}^{2*}$ to the LDC government to give subsidy to the LDC old generation t. The disaster reserve do face constraint in making loans, $\sigma_t \le \overline{\sigma}_{t+1} = s_{2,t+1}^{2*} + \mathrm{Z}_{t+1}$. Therefore, the actual subsidy that a LDC individual can get from the government is $\min[\overline{\sigma}_{t+1}, \sigma_t(\tau_t^*)]$, in which τ_t^* is the first-best amount of tax that allows a LDC individual to fully diversify his/ her risk. Give this fact, when a LDC individual makes portfolio, he has to know two pieces of information: the payment capacity of the DR in the coming period and how much the foreign young generation is willing to invest in the DC. Both pieces of information, however, is difficult to get access to for the LDC young generation who are making investment decisions. The current setting of the model does not allow us to answer this. As a compromise it is assumed that the LDC government carries out a policy stating that only presently kept liquid fund in the DR is going to be used in subsidizing disaster victims. This compromise discounts the effectiveness of the inter-generational instrument but it helps our description.

We use the same functions and parameters and calculate numerical results (Table 6-3). Since in this case it is assumed that the LDC government is holding liquid capital $\mathrm{Z}_t = 2$ which is then invested in the DC, the result in Table 6-3 is not directly comparable with those in Table 6-1 and 6-2. In order to compare across cases, numerical results of the benchmark case and international insurance case are re-computed by arbitrarily setting $k_{t+1}^2 = s_{2,t}^2 + \mathrm{Z}_t$ for both cases. Note that this setting is purely for comparison. The results are put in Table 6-4 and Table 6-5.

Table 6-3 Numerical results of inter-generational diversification system

Example *No.*	w_1^t	w_2^t	$s_{1,t}^{1*}$	σ_t^*	$s_{1,t}^{2*}$	$s_{2,t}^{2*}$	R_{t+1}^2	$R_{t+1}^{1,0}$	$R_{t+1}^{1,1}$	$\mathrm{E}U^{1*}$	$\mathrm{E}U^{2*}$
1	5	5	4.67	1.67	0.00	5.00	1.136	1.214	0.714	1.7096	1.7373
2	5	10	4.64	1.81	0.68	9.32	1.086	1.188	0.688	1.6873	2.3848
3	5	15	4.61	1.93	1.40	13.60	1.063	1.166	0.666	1.6683	2.7689
4	5	20	4.60	2.00	1.95	18.05	1.049	1.153	0.653	1.6565	3.0436
5	5	25	4.59	$\boxed{2.04}$	2.37	22.63	1.040	1.144	0.644	1.6486	3.2582
			4.60	2.00	2.36	22.64	1.040	1.144	0.644	1.6486	3.2582
6	6	15	5.53	$\boxed{2.34}$	0.67	14.33	1.060	1.161	0.661	1.8463	2.7659
			5.60	2.00	0.61	14.39	1.060	1.161	0.661	1.8459	2.7659
7	6	20	5.52	$\boxed{2.42}$	1.18	18.82	1.047	1.149	0.649	1.8358	3.0417
			5.60	2.00	1.11	18.89	1.047	1.149	0.649	1.8352	3.0417
8	6	25	5.51	$\boxed{2.47}$	1.58	23.42	1.039	1.141	0.641	1.8286	3.2568
			5.60	2.00	1.49	23.51	1.039	1.141	0.641	1.8279	3.2568
9	6	30	5.50	$\boxed{2.51}$	1.90	28.10	1.033	1.135	0.635	1.8234	3.4334
			5.60	2.00	1.80	28.20	1.033	1.135	0.635	1.8225	3.4334
10	6	35	5.49	$\boxed{2.54}$	2.16	32.84	1.028	1.131	0.631	1.8194	3.5833
			5.60	2.00	2.06	32.94	1.028	1.131	0.631	1.8185	3.5833

Note: The ration between tax and subsidy is set at $\pi(1)$. The amount of liquid capital saved in the Disaster Reserve as well as the maximal subsidy amount is assumed to be 2.

Table 6-4 Numerical results of benchmark case compatible to the inter-generation case

Example *No.*	w_1^t	w_2^t	$s_{1,t}^{2*}$	$s_{2,t}^{2*}$	R_{t+1}^2	$R_{t+1}^{1,0}$	$R_{t+1}^{1,1}$	$\mathrm{E}U^{1*}$	$\mathrm{E}U^{2*}$
1	5	5	0.00	5.00	1.125	1.200	0.700	1.684	1.7272
2	5	10	0.35	9.66	1.079	1.187	0.687	1.672	2.3789
3	5	15	1.05	13.95	1.059	1.165	0.665	1.650	2.7657
4	5	20	1.58	18.42	1.047	1.152	0.652	1.637	3.0416
5	5	25	1.99	23.01	1.038	1.143	0.643	1.628	3.2568
6	6	15	0.24	14.76	1.056	1.160	0.660	1.828	2.7629
7	6	20	0.74	19.26	1.045	1.148	0.648	1.816	3.0398
8	6	25	1.12	23.88	1.037	1.140	0.640	1.808	3.2555
9	6	30	1.43	28.57	1.032	1.135	0.635	1.802	3.4325
10	6	35	1.68	33.32	1.028	1.130	0.630	1.797	3.5826

Note: This is not the true benchmark case but one purely for comparison with the inter-generational case. It is assumed that the LDC government is investing in the DC with capital amount to 2.

Table 6-5 Numerical results international insurance case compatible to the inter-generational case

Example *No.*	w_1^t	w_2^t	$s_{1,t}^{1*}$	ν	m_t^*	$s_{1,t}^{2*}$	$s_{2,t}^{2*}$	R_{t+1}^2	$R_{t+1}^{1,0}$	$R_{t+1}^{1,1}$	$\mathrm{E}U^{1*}$	$\mathrm{E}U^{2*}$
1	5	5	4.67	0.202	1.614	0.00	5.33	1.120	1.214	0.714	1.7086	1.7385
2	5	10	4.69	0.210	1.499	0.38	9.94	1.077	1.197	0.697	1.6921	2.3852
3	5	15	4.66	0.211	1.610	1.11	14.23	1.058	1.173	0.673	1.6709	2.7695
4	5	20	4.64	0.211	1.692	1.66	18.70	1.046	1.159	0.659	1.6579	3.0442
5	5	25	4.63	0.210	1.755	2.09	23.28	1.038	1.149	0.649	1.6492	3.2587
6	6	15	5.59	0.211	1.953	0.30	15.11	1.055	1.170	0.670	1.8501	2.7664
7	6	20	5.57	0.210	2.047	0.83	19.61	1.044	1.156	0.656	1.8382	3.0422
8	6	25	5.55	0.210	2.120	1.24	24.20	1.037	1.147	0.647	1.8302	3.2573
9	6	30	5.54	0.209	2.179	1.57	28.88	1.031	1.140	0.640	1.8244	3.4339
10	6	35	5.53	0.209	2.227	1.85	33.62	1.027	1.135	0.635	1.8201	3.5837

Note: This is not the true international insurance case but one purely for comparison with the inter-generational case. It is assumed that the LDC government is investing in the DC with capital amount to 2.

It can be easily found that the inter-generational instrument, which is equivalent to the fair insurance program when there is no liquidity or credit constraint (numerical results No. 1~4 in Table 6-3), diversifies the risk fully for LDC individuals. According to our assumption, the subsidy capacity is set to be equal to the capital kept in the reserve, 2. In this sense, in numerical results No. 5~10 LDC individuals cannot meet their first-best demand for diversification. There are two series of result for No. 5~10, with the upper one showing the first-best choice while the lower one showing the result binding at the maximal subsidy amount.

Comparing the welfare states of individuals across three tables, it can be found that the benchmark case exhibits the lowest economic efficiency, as there is no means for risk transfer or diversification for LDC individuals. It is interesting to find out that the inter-generational approach, which is equivalent to fair-premium-rate insurance, does not lead to first-best equilibrium! The reason is not difficult to find. In this small two-country economy, when the risk financing choice of the LDC individual changes, the investment behavior of the DC individuals will change correspondingly and finally the improvement in the welfare state of the LDC individuals may be offset by such responses. Evidence can be found by comparing numerical results in Table 6-3 and 6-5. In results No. 1, the amount of investment to the LDC of DC individuals does not change. In this sense, LDC individuals are better off with the inter-generational approach than with the international insurance. From results No. 2, foreign investments from DC individuals are always higher in Table 6-3 than in Table 6-5. Obviously, it is the increase in DC individuals' investment that offsets a part of the effect. In this sense, the inter-generational approach is not necessarily a perfect substitution for international private insurance, for both the subsidy capacity issue and the offsetting issue.

Another thing worth noting is that DC individuals may not be delighted with the investment from LDC disaster reserve because it causes negative externality on their welfare states. Once the capital in the disaster reserve is invested in the DC, the domestic rate of return of investment of the DC will drop. DC individuals are then forced to restructure their investment portfolios and take more risk. It can be seen that among the welfare state of DC individuals is the lowest in Table 6-3 out of three tables. Here may raise the doubts that why DC individuals allow such kind of foreign investment. Think the question over and it can be found that only the elder generation of DC is not delighted to accept such investment. The younger generation of DC is happy with it. When capital investment increases, the return to investors drops but the labor income of the young generation increases. From the angle of long-run economic development, the DC government will also be happy to accept this investment.

6.6 OPTIMAL COMBINATION OF INTER-GENERATIONAL AND INTERNATIONAL INSTRUMENTS

In previous sections, it has been proved that both international private insurance and domestic disaster reserve can help LDC individuals transfer or diversify their disaster risk. In spite of the high premium rate, the advantage of private insurance is that one can buy as much as one wishes as long as one can afford. In contrast to private insurance, the "price" of the government subsidy is fair and it can perfectly diversify the risk along the time dimension, if no constraint is assumed. When there is an upper bound of subsidy, its effect will be discounted. Here rises the question of how the two instruments can be combined so that the disaster risk of the LDC is maximally diversified.

In order to discuss the questions raised above, the model is simplified to a partial equilibrium because of the information problem mentioned above. In the simplified model international financial institutions are introduced into the system to provide financial services to governments, for instance, the World Bank or Asian Developing Bank. They are supposed to provide loans at a reasonable interest rate. In this way we diminish the ambiguous setting in the information on maximum capacity of the subsidy, $\bar{\sigma}$, which depends on the capital available in the reserve, Z_t, and the capacity of all loans available, ζ. Generally ζ depends on the credit of the state, which is a common knowledge to its citizens. Given the information and the maximal capacity of the subsidy, individuals can decide the optimal amount of insurance to purchase.

With the modification, there are two approaches for private insurance market and the state disaster reserve to work together. One way is that the government puts the disaster reserve system in the form of public insurance which offers fair-rate-low-coverage insurance. LDC individuals then choose between domestic public insurance and international private insurance contracts. The international private insurance, of course, is expensive but unlimitedly supplied, as long as individuals can afford the up-going premium rate when demand goes high. With public insurance system, the budget constraint of the LDC individual is

$$\begin{aligned} w_t^1 &= s_{1,t}^1 + \nu m_t^1 + \tau_t \\ c_{t+1}^{1,j} &= R_{t+1}^{1,j} s_{1,t}^1 + j \cdot \left[m_t^1 + \sigma\left(\tau_t\right) \right], \text{ for } j = 0, 1 \\ m_t^1 &\geq 0, \sigma\left(\tau_t\right) \leq \bar{\sigma}_{t+1} \end{aligned} \tag{6.22}$$

Corresponding decision variables are $s_{1,t}^1$, m_t^1, and τ_t. First-order conditions for maximization requires that

$$\frac{u'\left(c_{t+1}^{1,0}\right)}{u'\left(c_{t+1}^{1,1}\right)} = \frac{1-\pi(1) R_{t+1}^{1,1}}{\pi(0) R_{t+1}^{1,0}} = \frac{\pi(1)}{\pi(0)} \frac{1-\nu R_{t+1}^{1,1}}{\nu R_{t+1}^{1,0}} \tag{6.23}$$

Giving the same specification as previous cases, numerical examples are given in Table 6-6.

Table 6-6 Numerical results of optimal combination of international and inter-generational approaches

Example *No.*	w_1^t	w_2^t	$s_{1,t}^{1*}$	ν	m	σ_t^*	$s_{1,t}^{2*}$	$s_{2,t}^{2*}$	R_{t+1}^2	$R_{t+1}^{1,0}$	$R_{t+1}^{1,1}$	$\mathrm{E}U^{1*}$	$\mathrm{E}U^{2*}$
1	5	5	4.67	0.200	0.882	0.784	0.00	5.18	1.136	1.214	0.714	1.710	1.739
2	5	10	4.65	0.200	0.894	0.849	0.34	9.84	1.083	1.200	0.700	1.698	2.384
3	5	15	4.62	0.200	0.571	1.327	1.21	13.90	1.062	1.171	0.671	1.673	2.769
4	5	20	4.60	0.200	0.307	1.678	1.85	18.21	1.049	1.155	0.655	1.659	3.044
5	5	25	4.59	0.200	0.095	1.945	2.33	22.69	1.040	1.145	0.645	1.649	3.258
6	6	15	5.54	0.200	0.896	1.408	0.44	14.74	1.059	1.167	0.667	1.851	2.766
7	6	20	5.52	0.200	0.659	1.740	1.04	19.09	1.047	1.152	0.652	1.839	3.042
8	6	25	5.51	0.200	0.466	1.994	1.50	23.60	1.038	1.143	0.643	1.830	3.257
9	6	30	5.50	0.200	0.309	$\boxed{2.193}$	1.85	28.21	1.033	1.136	0.636	1.824	3.433
			5.50	0.201	0.474	2.000	1.82	28.28	1.033	1.137	0.637	1.825	3.433
10	6	35	5.49	0.200	0.180	$\boxed{2.526}$	2.13	32.91	1.028	1.131	0.631	1.825	3.583
			5.50	0.201	0.488	2.000	2.08	33.02	1.028	1.132	0.632	1.820	3.583

Note: The amount of maximum payment capacity of the disaster reserve is assumed to be $\bar{\sigma} = 2$.

There are two series of results for specification No. 9 and 10 which exactly show the impact of the capacity constraint of the disaster reserve. Intuitively, if the investment behavior of the DC individuals do not change, LDC individuals are worse off when they can not meet their optimal level of coverage (full coverage for the disaster reserve system). In result No. 9 it is not the case because lower public insurance coverage for LDC individuals changes the investment behavior of DC individuals, which finally offset the negative impact of partial public insurance coverage. In result No. 10, it necessarily holds that LDC individuals are sub-optimal since they cannot enjoy full public insurance coverage.

When the capacity of disaster reserve allows LDC individuals to enjoy full public insurance coverage, the premium rate of international insurance contract also goes down to the fair rate. This result is beyond what we have expected that an individual buys “cheaper” public insurance coverage first and then “more expensive” international insurance when his coverage is in short. The interesting point is why DC individuals underwrite insurance contract at the fair premium rate. The equilibrium shows that they are willing to exchange insurance contract at the fair rate to hold a share of insurance premium revenue and later invest the capital optimally. If they deny doing so, LDC individuals choose to fully insure their risk by joining the public insurance program and all insurance revenue goes to the Disaster Reserve which are invested to the DC later. In this sense, DC individuals have to passively accept lower domestic rate of return of capital investment, which is definitely inferior to the previous choice. Therefore, the existence of domestic public insurance program not only provides fair insurance coverage but also forces international insurers to lower the premium rate. Even when the capacity of pubic insurance program is limited (please refer to result No. 9 and 10), premium rate of the international insurance is still lowered, although not fair any more.

Another approach is to follow the popular premium subsidy system. The government uses the disaster reserve system to give subsidy on private insurance contract, so the effective premium rate goes down and policyholders can enjoy cheaper insurance. For instance, for each unit of international insurance coverage m, the government attaches an extra coverage of $p \cdot m$ which comes from the disaster reserve system. In this sense, the budget constraint of the LDC individual changes to

$$\begin{aligned} w_t^1 - \tau_t &= s_{1,t}^1 + \nu m_t^1 \\ c_{t+1}^{1,j} &= R_{t+1}^{1,j} s_{1,t}^1 + j \cdot [1+p] m_t^1 \text{, for } j\text{=0, 1} \\ \pi(1) p m_t^1 &\le \tau_t \end{aligned} \tag{6.24}$$

with decision variables of $s_{1,t}^1$ and m_t^1. In (6.24), τ_t is a lump-sum income tax imposed uniformly on every individual in the LDC. It is officially determined and not a decision variable of the individuals anymore. The system in (6.24) is equivalent to have policyholders premium subsidy at the rate of $p/(1+p)$, since the effective premium rate is $\nu/(1+p)$. If system (6.24) is adopted, the government has more jobs to do than the case in (6.22) as it has to find out the optimal intervention strategy $p^* = p(\tau_t^*)$ which exactly delivers the identical equilibrium as in the other case. The relationship is $p^* = \sigma(\tau_t^*)/m^* = \tau_t^*/(\mu m^*)$. There is some difference between the mechanism proposed here and government-sponsored private insurance programs being operated in many countries. In general government-sponsored private insurance programs, it is the private insurance companies who are pooling and managing the risk. In the context of this model, there are two kinds of pools for diversifying the risk, the pool of the insurance companies and the disaster reserve operated by the LDC government.

6.7 SUMMARY

This chapter has focused on the inter-temporal aspect of disaster risk diversification, with a "one-good, two-country, two-period overlapping generations" model. The inter-temporal approach, which is termed "inter-generational disaster risk diversification" in the context of the model, is based on the classic "buffer-stock" strategy. It requires a disaster reserve which holds an amount of liquid capital and international lenders to provide a contingent capital to fill the resources gap. The model has found that, in perfect conditions that a disaster reserve can get access to unlimited loans, the inter-generational approach is equivalent to fair-premium-rate insurance. The disaster reserve serves as a risk neutral pool that absorbs all risks. International first-best disaster insurance market is not able to fully diversify the risk because insurance suppliers are exactly taking the risk through other channels. This alternative risk-taking approach has significant impact on the risk-sharing between two countries, which can even partially offset the effect of risk neutral disaster reserve. The result of the model further implies that the inter-generational approach cannot be a perfect substitution for private international insurance. On the one hand, subsidy capacity of the inter-generational instrument is generally limited as it does face constraints in making loans. On the other hand, the investment behavior of the disaster reserve will force international insurance suppliers to change their investment portfolio and offset the benefit brought by the disaster reserve. The last but not least finding is that when the inter-generational approach is put into the market in the form of public insurance, it forces international private insurers to lower their premium rates. If the capacity of disaster reserve allows providing full-cover public insurance, premium rate of the private insurance also goes down to the fair level.

The essential contribution of the model in this chapter is on the dynamic funding process of the inter-generational approach, which is of both academic and practical meaning. It reveals the reason why inter-temporal diversification of disaster risk at the individual level is so limited. Meanwhile, it provides the key relationship between in-flow and out-flow of capital in the buffer-stock strategy. The dynamic funding process of the financial disaster reserve can be modified to be accommodated to the context of grain reserve in Chapter 5. One simple way is just to change the interest rate in (6.14) to be the perishable rate of grains kept in barns.

The model presented here has been constructed more in the sense of economic theory. In order to keep the dynamic funding process general and universal we have sacrificed a lot of details in formulating the funding process of the disaster reserve. This fundamental model will have to be refined by taking many factors and constraints into account if applied to more practical cases. Moreover, when it comes to the design of a practical disaster reserve as the kernel of national disaster risk financing system, more elements and instruments must be taken into account and synchronized as a system, for instance, private and public insurance system at the lower layer, contingent credit and international reinsurance at the mid layer, and CAT bonds and other types of securitization at the top layer.

Chapter 7

Conclusion and discussion

7.1 MODEL FINDINGS

This thesis contains four independent but inter-linked analytical models covering four aspects of inter-sectoral and inter-temporal diversification of disaster risk. The inherent assumption throughout this thesis is that the diversification of disaster risk must be put into the context of economic development with resources allocation for production and wealth redistribution for consumption. It has successfully provided some insights into the factors that caused the failure or undermines the efficiency of disaster insurance market. Explicit findings of models can be highlighted as below.

1) In a dual-economy with disaster risk and *ex ante* and circular seasonal move between regions, social optimal allocation of risk and resources requires that a) the labor for production has to be allocated to equalize the marginal social benefit and cost of the marginal migrant, and b) redistribution of goods for consumption must have the weighted marginal *ex ante* utility equalized across all types of individuals. Signals from the relative price in the two goods markets are not enough to derive efficient allocation in all cases. Disaster insurance market with the first-best Malinvaud-Arrow insurance is necessary. Labor mobility in the form of lump-sum transaction costs is not going to induce externality and the insurance market can exactly lead to social optimal allocation of risks and resources. When goods tradability is taken into account, however, externalities are generated and insurance market may lose its efficiency. Government intervention, either in the form of lump-sum transfer or direct subsidy to disaster insurance premium, is able to modify the equilibrium to reach the first-best equilibrium.

2) In a closed dual-economy where the purely competitive goods markets are supposed to be cleared period-by-period, the producers of the inelastically demanded products (agriculture product in the model) bear much less disaster risk that destroys a part of output than the consumers. Producers can enjoy higher product revenue when the harvest is not so good because the rise in state-contingent price will offset the fall off in revenue induced by reduced output. If individuals

are assumed to be risk averse, then domestic insurance against the loss induced by disaster for producers is not possible.

If disaster insurance against the loss is provided by some international insurers, government subsidy which lowers the effective premium rate does attract more laborers to be engaged in agriculture production. It, however, does not necessarily encourage producers to increase their output level. If the product revenue is higher when disasters happen than the case they do not occur, partial coverage insurance only let producers to reduce their output level. They will produce the minimal amount when they are indifferent of purchasing full and partial coverage. Only if the product revenue is higher when disasters do not happen (for instance, because of government intervention), or government subsidy is substantially high, premium subsidy can encourage rural producers to produce more output.

3) In the same economy as described in point 2), if the inelastically demanded product refers to grain and the government is allowed to store grain for multi-periods, the disaster risk can be diversified to the time-dimension and re-allocated between producers and consumers. The social optimum requires the risk to be fully diversified to the time dimension so that aggregate market supply of grain is equalized across states. Intra-period resources allocation for production and wealth redistribution for consumption follows the same rule as mentioned in point 1). Full-cover social insurance system can exactly derive the social optimum.

The government can allow domestic disaster insurance market to emerge through intervention that re-allocates risk between producers and consumers. If the government adopts intervention strategy following non-arbitrage transaction, when it diversifies the risk to the time dimension, it simultaneously shifts the risk back to producers. Then urban consumers are able to offer disaster insurance to producers if rural producers end up with bearing more risks than them. The optimal but budget-infeasible intervention strategy is to stabilize aggregate market supply of grains. Meanwhile, it over-shifts the risk back to producers as the price of grains when disasters do not happen is higher than that when disasters happen (when state-contingent prices are equalized, consumers are exactly risk-free and all risks are shifted back to producers). The risk can then be re-allocated between producers and consumers through the insurance market. In this sense, first-best-insurance equilibria under intervention can derive the social optimum.

4) Inter-temporal disaster diversification is of great significance to risk reduction. Individuals and private insurers are not able to make full use of the buffer-stock strategy because of limited life time and credit. In a one-good, two-country, and two-period overlapping generations economy, the government of the disaster-damage-prone country can apply the buffer-stock strategy by setting up a disaster reserve and getting access to international loans from the foreign country. In case that there is neither credit constraint for this government nor upper-limit of international loan, the disaster reserve can serve as a risk-neutral pool and absorb all disaster risks at fair costs. The weakness of inter-temporal approach, compared to private insurance contracts, is its limited coverage available. If the government offers the inter-temporal instrument in the form of public

disaster insurance to its citizens, in the context of this two-country model, it leads not only to diversifying the risk but also to forcing international insurers to lower their premium rate. Consequently, the optimal combination of inter-temporal and international approaches maximally washes disaster risk away in this two-country economy.

7.2 POLICY IMPLICATIONS

1) Mutual insurance system is of great importance to rural producers.

This piece of policy implication is not derived from the explicit result of models but from the implicit assumption of models in Chapters 4 and 5. Let us compare between cases in which there is and there is no mutual insurance system. Since the social aggregate output of agriculture product is determined only by the collective state of the world, state-contingent prices have nothing to do with whether there exists a mutual insurance system or not. If there is no mutual insurance system, producers whose yields are damaged are likely to become the victims then. This is consistent with what we have observed in reality. However, if there is mutual insurance system, individual risks can be fully shared among producers and there will be no certain “loser” in the producer group. According to the result of the models, if there is no other government intervention on the supply or price of agriculture product, collective risk does not make trouble for rural producers at all.

Mutual insurance system also has its institutional advantages as compared to commercial insurance contract offered by insurance companies. Firstly, household-based transaction costs can be largely reduced. Mutual insurance system is commonly operated among rural producers of similar degree of exposure. They are probably from the same geographical regions or administration districts and people may know each other very well, for instance, from the same village or town. In this sense, the costs for collecting premium by insiders will be smaller than by insurance agents. Meanwhile, since rural producers know each other very well, the transaction costs for controlling moral hazard and adverse selection can be largely reduced. This point has been exactly employed by the advocates of group insurance, group loan, or micro-credit (e.g. Yu, 2008). Last but not least, according to the interview in the field survey conducted by the author (Ye, 2008), it seems that rural producers are more concerned about household-to-household disparity in terms of indemnity. In other words, they prefer “average” indemnity to each victim household of disaster irrespective of the real losses claimed. Mutual insurance system fits this type of recognition since according to our models it derives average labor income pattern. This point may induce incentive and moral hazards problems in production but reasonable deductable and coinsurance may work complementarily.

2) Direct subsidy to the premium of crop disaster insurance is not suggested.

Chapter 2 has listed various kinds of hypotheses advocating or explaining the motivation of giving direct subsidy to insurance premium paid by rural producers. If the intention of premium subsidy is to help the market to emerge, we may doubt the root cause for which the market fails to emerge. In the context of our models, first-best insurance market does not emerge only because rural producers have less desire to get insured than urban consumers. If this is true in an economy, then the government should think carefully about how to insure the risks borne by the urban consumers.

If the intention of premium subsidy is to control migration or seasonal move, premium subsidy can be one way to serve the purpose. Nevertheless, a question still remains why the government does not simply use lump-sum transfer which is neutral and more efficient.

If the intention of premium subsidy is to create incentives to encourage rural producers to increase their output level, it probably leads to an undesirable consequence. From the result of models we know that if the premium subsidy is to allow producers to enjoy full coverage, it reduces per capita output level if the realized profit of farming is worse when there is a good harvest. Therefore, for the sort of agriculture products which show the "harvest poor" phenomenon, premium subsidy goes against the intention of the government.

3) First-best disaster insurance market is in need of government intervention to fulfill the role of risk and resources allocation in most cases.

In the trade-off between self-sufficiency of foodstuffs and rural-urban disparity in labor income and risk-bearing, first-best disaster insurance market could balance between the trade-off when ideal conditions are met. Imperfect goods tradability is one of the factors that may undermine the efficiency of the disaster insurance market in doing so. When the transaction costs for shipping goods are positive, the right government policy depends on how large frictions rural residents are facing when they try to move to work in the urban sector. If the goods are assumed to be normal goods and the transaction costs for the migration are low, the rural sector is likely to be under-populated and therefore migration should be discouraged through intervention policies. If it is high, the rural sector is then likely to be over-populated and therefore migration should be encouraged. When the product of the rural sector refers to inelastically demanded agriculture products, it is more likely to be the opposite case that the rural sector is over-populated, because individuals are fear of shortage of agriculture product which is far more important than the urban goods.

This thesis, however, cannot provide further insights into this issue because of the lack of more detailed context and empirical estimation. The models presented in the thesis are not yet able to address the criteria of "high" or "low". Meanwhile, the reality is often masked by complexity of the socioeconomic system and layers of institutional arrangements. The structure of the model may be over simplified and assumptions are too strong to derive more practical implications into the actualities behind.

4) Disaster reserves operated by governments are of great practical meaning for financing disaster risk.

Government pooling of disaster risk can be directly offered to damage-prone individuals in the form of fair-premium rate and low-coverage public insurance, or it can be used to provide primary insurers with re-insurance coverage. The credit of the government in making loans is of vital importance to the capacity of disaster reserve in diversifying the risk inter-temporally.

Disaster reserve suggested in this thesis may be different from existing systems operated in some countries. For instance, in the CAPIP, provincial governments are establishing catastrophic reserve for coming peak losses. The liquid capital kept in the reserve comes from the premium revenue of insurance companies, except that a part of the premium comes from tax-payers. In this sense, the government only plays the role of "looking after" liquid capital for insurance companies. The essence of inter-temporal diversification or disaster reserve, however, is to let the government use financial resources collected from tax-payers to pool the risk besides private insurance pools. For instance, the Japanese government exactly follows this approach in its national earthquake insurance system, as stated at the end of Chapter 2.

When disaster reserve is applied to the risk reduction in market supply of agriculture products, it is important to be aware that the buffer-stock strategy regarding grain storage is not as simple as the one with liquid fund because the price system will be affected. It not only diversifies the risk to the time dimension but also re-allocates the risk between rural producers and consumers. The government should organize the intervention strategy carefully and attach sufficient attention on its redistribution effect.

7.3 BEYOND THIS THESIS

Although some significant findings and policy implications have been derived from the models presented in this thesis, the extent to which this thesis covers is still limited, neither academically nor practically. There is yet a long way for the author to go before the study comes down to cases and hit the core of the art of financing disaster risk.

One priory issue that has to be handled in the near future is to verify the models with econometric analysis, although models in this thesis are formulated by following classical and verified assumptions. Econometric works on field observed data must follow up so that the models can be tested in a specific socioeconomic context. Thus model findings may guarantee a higher degree of applicability.

The second issue may be the scale of abstraction. Economics is a discipline or an art with highly abstraction of the real world. Disaster risk management, however, is more problem-oriented. It seems that this thesis to some extent has compromised between the level of details and degree of abstraction. The author may have to firstly to solve a number of practical problems and to go into depth of specific appearance in reality before generalizing models. For instance, when it comes to the grain policy, it needs to consider specific policies being carried out by governments. As for the dynamic funding process of disaster reserve, it is better to take institutional issues into account. With these details accommodated, changes in model assumptions may have substantial impact on the explicit results of models, and consequently derive different policy implications.

Future research interests of the author based on the findings of the models and in a more specific manner include the following points:

1) The question addressed in Chapter 3 has not provided a satisfactory answer. A refined version of the theoretical model with CGE analysis by taking China's specific situation into account is needed. Then it may possibly enable us to provide the criteria of identifying "high" or "low" of the transaction costs that Chinese rural labors are charged for the seasonal move.

2) It is necessary to identify the property of existing crop insurance programs. The structure of Arrow-Debreu economy determines that the insurance contract is based on individual-to-individual exchange. It is straightforward to tell the difference between insurance contracts within an individual group (mutual insurance system) and cross-individual groups. In reality, it is the insurance company who collects premium and diversify risks. It is difficult to tell whether crop insurance programs are more in the sense of mutual insurance that diversifies disaster risks among rural producers or cross-group insurance which transfers risks to urban consumers without sound auditing of business books. With this step, policy implication provided in the previous section can be of higher practical meaning.

3) In Chapter 4 we have put several strong assumptions regarding moral hazards that there is a well-functioning incentive system that prevents the problem from happening. In reality, it has been repeatedly reported by insurers that they are exactly suffering a lot. In the field survey conduct by the author in 2008, insurance managers provided plenty of stories that farmers intentionally reduced output level or took less care of their crops so that both the probability and the amount of indemnity rise up. The assumed well-functioning incentive system has to be worked out and it will be of substantial contribution for primary insurers.

4) In Chapter 5 we have held a preliminary discussion on the relationship between grain reserve policy and crop insurance market. The analysis was conducted in quite a general manner. None-arbitrage operation is simply an ideal and theoretical approach which follows the principle of financial engineering. Specific policy instruments adopted in China, Japan, the U.S., and other countries and regions in the world may largely vary. For instance, in China the grain reserve policy is more like a free put option that the government provided to rural producers. The relationship among grain policy, crop insurance as well as other fiscal or policy instruments has to be refocused with more details of the economic context.

5) Throughout this thesis, Arrow-Debreu economy with complete markets is assumed. This generates a big gap between models here and the reality since in real world our markets for trading state-contingent commodities are far less than the states of nature. This essential structural difference may provide us more alternative answers on the risk-sharing puzzle and derive more important roles that the government is supposed to fulfill.

APPENDIX I

Given the optimization problem on consumption below:

$$\max u(x,y) = b\frac{x^{1-\frac{1}{\alpha}}-1}{1-\frac{1}{\alpha}} + y, 0<\alpha<1$$

subject to:

$$px + y = e$$

When interior solution is assumed, the optimal choice can be derived as:

$$x^* = bp^{-a}, y^* = e - bp^{-a+1}$$

Then the indirect utility function can be put as:

$$v(e,p) = e - \frac{b^{\alpha}p^{1-\alpha}-\alpha b}{1-\alpha}, 0<\alpha<1.$$

The income elasticity of demand can then be derived as:

$$\epsilon_x^e = \frac{dx^*}{de}\frac{e}{x} = 0$$

In order to derive the price elasticity of demand, we use the Slutsky equation:

$$\frac{dx^*}{dp} = \frac{\partial h\left(p^*, v(p,e)\right)}{\partial p} - \frac{\partial x^*\left(p^*, m^*\right)}{\partial m}x^*$$

From the income elasticity of substitution we know that the second item on the *r.h.s.* is 0. The expenditure function to maintain a certain utility level $\overline{v}$ is:

$$e\left(p^*, \overline{v}\right) = \overline{v} + \frac{b^{\alpha}p^{1-\alpha}-\alpha b}{1-\alpha}, 0<\alpha<1$$

Then the Hicksian demand function can be derived as:

$$h\left(p^*, \overline{v}\right) = p^{-\alpha}, 0<\alpha<1$$

Therefore, price elasticity of demand is:

$$\epsilon_x^p = \frac{dx^*}{dp}\frac{p}{x^*} = \frac{\partial h\left(p^*, v\right)}{\partial p}\frac{p}{x^*} = -\alpha, 0<\alpha<1$$

End of proof.

APPENDIX II

The first-order derivative of social aggregate utility with respect to effective premium rate can be derived by:

$$\begin{aligned}
\frac{dU_i}{d\nu} &= \frac{\partial U_i}{\partial X_i}\frac{\partial X_i}{\partial \nu} + \frac{\partial U_i}{\partial n_i}\frac{\partial n_i}{\partial \nu} + \frac{\partial U_i}{\partial \nu} \\
\frac{\partial U_i}{\partial X_i} &= \frac{b}{n_i {X_i}^2}\mathrm{E}\tilde{\delta}^{-1} - c n_i \frac{\pi(1) - \nu}{\nu} \\
\frac{\partial U_i}{\partial n_i} &= -e_2 + \frac{b}{{n_i}^2 X_i}\mathrm{E}\tilde{\delta}^{-1} + \frac{\pi(1) - \nu}{\nu}\left(K - cX_i\right) > 0 \qquad \text{, for } i=fc,\ pc \\
\frac{\partial U_i}{\partial \nu} &= -\frac{n_i \pi(1)\left(K - cX_i\right)}{\nu^2} < 0
\end{aligned}$$

When partial coverage is purchased, we have:

$$\frac{\partial U_{pc}}{\partial X_{pc}} = \frac{b}{n_{pc}{X_{pc}}^2}\mathrm{E}\tilde{\delta}^{-1} - n_{pc} c \frac{\pi(1) - \nu}{\nu} = n_{pc}\left[\frac{\pi(1) c \mathrm{E}\tilde{\delta}^{-1}}{\nu \mathrm{E}\tilde{\delta}} - \frac{\pi(1) c}{\nu} + c\right] > 0$$

$$\begin{aligned}
\frac{\partial U_{pc}}{\partial n_{pc}} &= -e_2 + \frac{b\mathrm{E}\tilde{\delta}^{-1}}{n_{pc}^2 X_{pc}} + \frac{\pi(1) - \nu}{\nu}\left(K - cX_{pc}\right) = -e_2 + \frac{b\mathrm{E}\tilde{\delta}^{-1}}{n_{pc}\nu^{\frac{1}{2}}\phi} - K + c\frac{\nu^{\frac{1}{2}}\phi}{n_{pc}} + \frac{\pi(1)}{\nu}\left(K - cX_{pc}\right) \\
&= -\left(e_2 + K\right) + b\mathrm{E}\tilde{\delta}^{-1}\frac{\left(e_2 + K\right)\nu - \pi(1)K}{\left[b\mathrm{E}\tilde{\delta}^{-1} - \pi(1)c\phi^2\right]\nu} + cX_{pc} + \frac{\pi(1)}{\nu}K - \frac{\pi(1)}{\nu}c\frac{\left[\left(e_2 + K\right)\nu - \pi(1)K\right]\phi^2}{\left[b\mathrm{E}\tilde{\delta}^{-1} - \pi(1)c\phi^2\right]} \\
&= -\left(e_2 + K\right) + b\mathrm{E}\tilde{\delta}^{-1}\frac{\left(e_2 + K\right)\nu - \pi(1)K}{\left[b\mathrm{E}\tilde{\delta}^{-1} - b\mathrm{E}\tilde{\delta}\right]\nu} + cX_{pc} + \frac{\pi(1)}{\nu}K - b\mathrm{E}\tilde{\delta}\frac{\left[\left(e_2 + K\right)\nu - \pi(1)K\right]}{\left[b\mathrm{E}\tilde{\delta}^{-1} - b\mathrm{E}\tilde{\delta}\right]\nu} \\
&= cX_{pc} > 0
\end{aligned}$$

$$\begin{aligned}
\frac{dU_{pc}}{d\nu} &= n_{pc}\left[\frac{\pi(1) c\mathrm{E}\tilde{\delta}^{-1}}{\nu\mathrm{E}\tilde{\delta}} - \frac{\pi(1) c}{\nu} + c\right]\frac{\partial X_{pc}}{\partial \nu} + cX_{pc}\frac{\partial n_{pc}}{\partial \nu} - \frac{n_{pc}\pi(1)\left(K - cX_{pc}\right)}{\nu^2} \\
&= n_{pc}\left[\frac{\pi(1) c\mathrm{E}\tilde{\delta}^{-1}}{\nu\mathrm{E}\tilde{\delta}} - \frac{\pi(1) c}{\nu}\right]\frac{\partial X_{pc}}{\partial \nu} + n_{pc}c\left[\frac{X_{pc}}{2\nu} - \frac{X_{pc}}{n_{pc}}\frac{\partial n_{pc}}{\partial \nu}\right] + cX_{pc}\frac{\partial n_{pc}}{\partial \nu} - \frac{n_{pc}\pi(1)\left(K - cX_{pc}\right)}{\nu^2} \\
&= n_{pc}\left[\frac{\pi(1) c\mathrm{E}\tilde{\delta}^{-1}}{\nu\mathrm{E}\tilde{\delta}} - \frac{\pi(1) c}{\nu}\right]\frac{\mathrm{E}\tilde{\delta}\left(e_2 + K\right)}{\pi(1) c\left[\mathrm{E}\tilde{\delta}^{-1} - \mathrm{E}\tilde{\delta}\right]} + n_{pc}c\frac{X_{pc}}{2\nu} - \frac{n_{pc}\pi(1)\left(K - cX_{pc}\right)}{\nu^2} \\
&= n_{pc}\frac{\left(e_2 + K\right)}{\nu} + n_{pc}c\frac{X_{pc}}{2\nu} - \frac{n_{pc}\pi(1)\left(K - cX_{pc}\right)}{\nu^2} \\
&= n_{pc}\frac{\left(e_2 + K\right)\nu - \pi(1)K}{\nu^2} + n_{pc}c\frac{X_{pc}}{2\nu} + \frac{n_{pc}\pi(1) cX_{pc}}{\nu^2} > 0
\end{aligned}$$

When full coverage is purchased:

$$U_{fc} = b + \left(1 - n_{fc}\right) e_2 - \frac{b}{n_{fc} X_{fc}} \mathrm{E}\tilde{\delta}^{-1} + n_{fc}\left[\pi(1) - \nu\right] \frac{\sigma \Delta K}{c + \nu \sigma \Delta}$$

$$\frac{\partial U_{fc}}{\partial X_{fc}} = \frac{b \mathrm{E}\tilde{\delta}^{-1}}{n_{fc} {X_{fc}}^2} > 0, \frac{\partial X_{fc}}{\partial \nu} = -\frac{K \sigma \Delta}{\left(c + \nu \sigma \Delta\right)^2} < 0$$

$$\begin{aligned}
\frac{\partial U_{fc}}{\partial n_{fc}} &= -e_2 + \frac{\left(e_2 + K\right)\left(c + \nu \sigma \Delta\right) - \pi(1) \sigma \Delta K}{c + \nu \sigma \Delta} + \left[\pi(1) - \nu\right] \frac{\sigma \Delta K}{c + \nu \sigma \Delta} \\
&= -e_2 + e_2 + K - \frac{\pi(1) \sigma \Delta K}{c + \nu \sigma \Delta} + \pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta} - \nu \frac{\sigma \Delta K}{c + \nu \sigma \Delta} \\
&= K - \nu \frac{\sigma \Delta K}{c + \nu \sigma \Delta} = c X_{fc} > 0
\end{aligned}$$

$$\begin{aligned}
\frac{\partial n_{fc}}{\partial \nu} &= \frac{1}{2 n_{fc}} \frac{b \mathrm{E}\tilde{\delta}^{-1}}{K} \frac{2\left(c + \nu \sigma \Delta\right) \sigma \Delta \left[\left(e_2 + K\right)\left(c + \nu \sigma \Delta\right) - \pi(1) \sigma \Delta K\right] - \left(c + \nu \sigma \Delta\right)^2 \left(e_2 + K\right) \sigma \Delta}{\left[\left(e_2 + K\right)\left(c + \nu \sigma \Delta\right) - \pi(1) \sigma \Delta K\right]^2} \\
&= \frac{1}{2 n_{fc}} \frac{b \mathrm{E}\tilde{\delta}^{-1} \left(c + \nu \sigma \Delta\right) \sigma \Delta}{K} \frac{\left[\left(e_2 + K\right)\left(c + \nu \sigma \Delta\right) - 2\pi(1) \sigma \Delta K\right]}{\left[\left(e_2 + K\right)\left(c + \nu \sigma \Delta\right) - \pi(1) \sigma \Delta K\right]^2} \\
&= \frac{1}{2 n_{fc}} \frac{b \mathrm{E}\tilde{\delta}^{-1} \sigma \Delta}{K} \frac{\left[\left(e_2 + K\right) - 2\pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta}\right]}{\left[\left(e_2 + K\right) - \pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta}\right]^2} \\
&= \frac{n_{fc}^3}{2} \frac{K \sigma \Delta \left[\left(e_2 + K\right)\left(c + \nu \sigma \Delta\right) - 2\pi(1) \sigma \Delta K\right]}{b \mathrm{E}\tilde{\delta}^{-1} \left(c + \nu \sigma \Delta\right)^3}
\end{aligned}$$

$$\frac{\partial U_{fc}}{\partial \nu} = -n_{fc} \frac{\sigma \Delta K}{c + \nu \sigma \Delta} - n_{fc}\left[\pi(1) - \nu\right] \frac{\sigma \Delta K \sigma \Delta}{\left(c + \nu \sigma \Delta\right)^2} = -n_{fc} \frac{c \sigma \Delta K + \pi(1) \sigma^2 \Delta^2 K}{\left(c + \nu \sigma \Delta\right)^2} < 0$$

$$\begin{aligned}
\frac{\partial U_{fc}}{\partial X_{fc}} \frac{\partial X_{fc}}{\partial \nu} + \frac{\partial U_{fc}}{\partial n_{fc}} \frac{\partial n_{fc}}{\partial \nu} &= -\frac{1}{n_{fc}} \frac{b \mathrm{E}\tilde{\delta}^{-1} \sigma \Delta}{K} + c X_f \frac{1}{2 n_{fc}} \frac{b \mathrm{E}\tilde{\delta}^{-1} \sigma \Delta}{K} \frac{\left[\left(e_2 + K\right) - 2\pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta}\right]}{\left[\left(e_2 + K\right) - \pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta}\right]^2} \\
&= -\frac{1}{n_{fc}} \frac{b \mathrm{E}\tilde{\delta}^{-1} \sigma \Delta}{K} \left[1 - \frac{c X_{fc}}{2} \frac{\left[\left(e_2 + K\right) - 2\pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta}\right]}{\left[\left(e_2 + K\right) - \pi(1) \frac{\sigma \Delta K}{c + \nu \sigma \Delta}\right]^2}\right] < 0
\end{aligned}$$

Therefore, it strictly holds that

$$\frac{d U_{fc}}{d \nu} < 0, U_{fc}\Big|_{\nu = 0} > U_0$$

APPENDIX III

Solving the differential equations with respect to y in following form

$$dy - rydt = mdt + ndN(t), \tag{A.1}$$

in which $dN(t)$ is used to denote a standard Poisson process. To solve the equation, firstly let the right hand side of the equation equals to 0 and we shall get a new differential equation with respect to y':

$$dy' - ry'dt = 0 \tag{A.2}$$

Integral both side of the equation we get

$$y' = Ce^{rt} \tag{A.3}$$

Let C be a function of t, $C = f(t)$ and insert it into (A.3), the solution for the linear differential (A.1) is actually $y = f(t)e^{rt}$. Differentiate it,

$$dy = f'(t)e^{rt}dt + f(t)re^{rt}dt \tag{A.4}$$

The property of Poisson process implies that $dN(t) \sim \mu dt$, in which μ is the intensity of the Poisson process. In this sense, (A.1) is equivalent to

$$dy - rydt = mdt + n\mu dt \tag{A.5}$$

By comparing (A.4) and (A.5) we can get the solution for the differential equation. As μdt is actually the expectation of $dN(t)$, the solution is also an expected value.

$$f(t) = -(m + n\mu)e^{-rt}/r \tag{A.6}$$

$$\mathrm{E}y = \left[-\frac{m + n\mu}{r}e^{-rt} + C'\right]e^{rt}, \tag{A.7}$$

in which C' is a constant. By giving the initial condition $y|_{t=0} = y_0$, we can solve for the constant C' and get the final solution for (A.1) as

$$\mathrm{E}y = \left[-\frac{m + n\mu}{r}\left(1 - e^{-rt}\right) + y_0\right]e^{rt}. \tag{A.8}$$

References

Acemoglu, D. and Robinson, J. A. (2001): Inefficient redistribution. *American Political Science Review* 95 (3), 649-661.

Arrow, K. J. (1996): The theory of risk-bearing: small and great risks. *Journal of risk and Uncertainty* 12, 103-111.

Bardsley, P., Abbey, A. and Davenport, S. (1984): The economics of insuring crops against drought. *Australian Journal of Agricultural Economics*, 28, 1-14.

Barnett, B. J. (2007): The U.S. federal crop insurance program. *Can. J. Agric. Econ.* 48 (4), 539-551.

Barnett, B.J., Skees, J. R. and Hourigan, J. D. (1990): Examining participation in Federal Crop Insurance. *Staff Paper No. 275*, Department of Agricultural Economics, University of Kentucky.

BBC News (2009): *China rural-urban wage gap widens*, January 16 2009. http://news.bbc.co.uk /2/hi/asia-pacific/7833779.stm, accessed on May 28th, 2009.

Becker, G. S. (1983): A theory of competition among pressure groups for political influence. *Quarterly Journal of Economics* XCVIII (3), 371-400

Bennett, J. and Dixon, H. D. (1996): A macrotheoretic model of the Chinese economy. *Journal of Comparative Economics* 22, 277-294.

Berliner, B. (1982): *Limits of Insurability of risks*. Englewood Cliffs.

Blanchard, O.J. and Fischer, S. (1989): *Lectures on Macroeconomics*. The MIT press, 49–50.

Carter, C. A. (1997): The urban-rural income gap in China: implications for global food market. *Amer J Agr Econ* 79 (5), 1410-1418.

Cass, D. et al. (1996): Individual risk and mutual insurance. *Econometrica* 64 (2), 333-341.

Cummings, J. D., Lalonde, D. and Phillips, R. D. (2002): Managing Risk using Index-linked Catastrophic Loss securities. In: Morton Lane edited *Alternative Risk Strategies*, 19-46, published by Risk Books.

Cummins, J. D. (2007): Reinsurance for natural and man-made catastrophes in the United States: current state of the market and regulatory reforms. *Risk Management and Insurance Review* 10 (2), 179-220.

Cummins, J. D. (2008): CAT bonds and other Risk-Linked Securities: state of the market and recent developments. *Risk Management and Insurance Review* 11 (1), 23-47.

Cummins, J. D. and Danzo, P.M. (1997): Price shocks and capital flows in liability insurance industry: Overview. *Journal of Financial Intermediation* 6, 3-38.

Cummins, J. D. and Doherty, N. A. (2002): Capitalization of the property-liability insurance industry: overview. *Journal of Financial services* 21 (1), 5-14.

Deaton, A. (1991): Saving and liquidity constraints. *Econometrica* 59, 1211-1248.

Dixit, A. K. and Londregan, J. B. (1995): Redistributive politics and economic efficiency. *American Political Science Review* 89, 856-866.

Doherty, N. A. (1997): Financial innovation in the management of catastrophic risk. Paper supported by the Wharton Financial Institution Center and the Wharton Risk Management and Decision Processes Center Project on “Managing Catastrophic Risk”. http://fic.wharton.upenn.edu/fic/papers/98/cat02.pdf, accessed on Apr 30, 2009.

Flatters, F. (1974): Public goods, efficiency, and regional fiscal equalization. *Journal of Public Economics* 3, 99-112.

Fraser, R. W. (1988): A method for evaluating supply response to price uncertainty. *Australian Journal of Agricultural Economics* 32, 22-36.

Froot, K. A. (1999b): The evolving market for catastrophic event risk. *NBER Working Paper No. 7287*, http://www.nber.org/papers/w7287, accessed on Apr 30, 2009.

Froot, K.A. (1999): *The financing of catastrophe risk*. The University of Chicago Press, 1-2.

Gao, Y. B. (2006): Economic analysis of failure in agricultural insurance market. *Journal of Northeastern University (Social Science)* 8 (6), 422-425. (In Chinese)

Gardner, B. L. and Kramer, R. A. (1986): Experience with crop insurance programs in the United States. In Hazell, P. et al. edited *Crop Insurance for Agriculture Development: Issues and Experiences*. Baltimore and London: the Johns Hopkins University Press, 195-222.

Glauber, J. W. (2004): Crop insurance reconsidered. *Amer. J. Agr. Econ.* 86 (5), 1179-1195.

Gollier, C. (1994): Insurance and precautionary saving in a continuous-time model. *Journal of Risk and Insurance* 61, 78-95.

Gollier, C. (2003b): To insure or not to insure?: an insurance puzzle. *The Geneva Papers on Risk and Insurance Theory* 28, 5-24.

Gollier, C. (2003b): Insurability. *Paper presented to the workshop of the NBER Insurance Project*, Boston, U. S., February 2002.

Goodwin, B.K. (1993): An empirical analysis of the demand for multiple peril crop insurance. *Amer. J. Agr. Econ.* 75, 425-434.

Goodwin, R. K. and Smith, V. H. (1995): *The Economics of Crop Insurance and Disaster Aid*. Washington, D. C: The AEI Press.

Goshay, R. and Sandor, R. (1973): An inquiry into the feasibility of a reinsurance future market. *Journal of Business Finance* 5 (2), 56-66.

Guha-Sapir, D., et al. (2004): *Thirty years of natural disasters 1974-2003: the numbers*. Presses Universitaires de Louvain.

Guy Carpenter & Company (2007): *U.S. reinsurance renewals at January 1, 2007: smooth sailing ahead*? New York: Guy Carpenter. http://gcportal.guycarp.com/portal/extranet/popup/pdf_2007/GCPub/Renewals%20Report%202007.pdf, accessed on Apr 28th, 2009.

Hare, D. (1999): "Push" versus "pull" factors in migration outflow and returns: determinants of migration status and spell duration among China's rural population. *Journal of Development Studies* 35 (3), 45-72.

Hazell, P. (1981): Crop insurance -- a time for reappraisal. *IFPRI report* 3, 1-4.

Hercowitz, Z. and Pines, D. (1991): Migration with fiscal externalities. *Journal of Public Economics* 46, 163-180.

Hertel, T. and Zhan, F. (2006): Labor market distortions, rural-urban inequality and the opening of China's economy. *Economic Modelling* 23, 76-109. doi: 10.1016/j.ecomod.2005.08.004

Holmstrom, B. (1979): Moral hazard and observability. *Bell Journal of Economics* 10 (1), 74-91.

Hoyois, P., et al. (2007): *Annual Disaster Statistical Review: numbers and trends* (2006). Center for Research on the Epidemiology of Disasters, School of Public Health, Catholic University of Louvain, Brussels, Belgium. http://www.emdat.be/Publications/publications.html, accessed on Jan 23, 2008.

Ibarra, H., and Skees, J. (2007): Innovation in risk transfer for natural hazards impacting agriculture. *Environmental Hazards* 7, 62-69.

Irz, X. and Roe, T. (2005): Seeds of growth? Agriculture productivity and the transitional dynamics of the Ramsey model. *European Review of Agricultural Economics* 32 (2), 143-165.

Ito, J. (2008): The removal of institutional impediments to migration and its impact on employment, production and income distribution in China. *Econ Change Restruct* 41, 239-265. doi: 10.1007/ s10644-008-9051-7

Jaegher, K. (2007): Benchmark two-good utility functions. *Utrecht School of Economics Discussion Paper Series 07-09*. http://www.uu.nl/uupublish/content/07-092.pdf, accessed on May 10, 2009.

Jaffee, D. M. and Russell, T. (1998): Can security markets save the private catastrophe insurance market? Paper prepared for *the 1998 Conference of the Asia-Pacific Risk and Insurance Association*, July19-22, 1998 Singapore. http://faculty.haas.berkeley.edu/JAFFEE/Papers/Singapore2.pdf, accessed on Apr 30, 2009.

Jaffee, D.M. and Russel, T. (1996): Catastrophe insurance, capital markets and uninsurable risks. Paper presented at *the Wharton Financial Institutions Center's May 1996 Conference on Risk Management in Insurance Firms.* http://fic.wharton.upenn.edu/fic/papers/96/9612.pdf, accessed on Jan 28th, 2008.

Johnson, D. G. (1993): Role of agriculture in economic development revisited. *Agricultural Economics* 8, 421-434.

Johnston, B. F. and Mellor, J. W. (1961): The role of agriculture in economic development. *Amer. Econ. Rev.* 51, 566-593.

Jones, K. (2007): Catastrophe insurance in Asia – where to from here? Presentation at *the First International Conference on Asia Catastrophe Insurance*, December 3-4, 2007 in Kyoto, Japan.

Kleindorfer, P. and Kunreuther, H. (1999): The complementary roles of mitigation and insurance in managing catastrophic risks. *Risk Analysis* 19 (4), 727-738.

Koskelaa, E. and Puhakkab, M. (2007): Stone–Geary preferences in overlapping generations economies under pure exchange: a note. *Journal of Macroeconomics* 29 (4), 976-982.

Kostov, P. and Lingard, J. (2004): Subsistence agriculture in transition economics: its roles and determinants. *J. of Agri. Econ.* 55 (3), 565-579.

Kunreuther, H. (2000): Insurance as cornerstone for public-private sector partnerships. *Natural Hazards Review* 1 (2), 126-136.

Kunreuther, H. (2001): Incentives for mitigation investment and more effective risk management: the need for public-private partnerships. *Journal of Hazardous Materials* 86, 171-185.

Kunreuther, H. C. and Linnerooth-Bayer, J. (2003): The financial management of catastrophic flood risks in emerging-economy countries. *Risk analysis* 23 (3), 627–639.

Kunreuther, H., Hogarth, R.M., and Meszaros, J. (1993): Insurer ambiguity and market failure. *Journal of Risk and Uncertainty* 7, 71-87.

Kunreuther, H., Meszaros, J., Hogarth, R.M., and Sprance, M. (1995): Ambiguity and underwriter decision processes. *Journal of Economic Behavior and Organization* 26, 337-352.

Linnerooth-Bayer, J. and Mechler R. (2007): Disaster safety nets for developing countries: extending public-private partnerships. *Environmental Hazards* 7, 54-61.

Linnerooth-Bayer, J. et al. (2007): Disaster risk management: pro-active financing to reduce vulnerability. *Environmental Hazards* 7, 1-6.

Mahul, O. and Gurenko, E. (2006): The macro financing of natural hazards in developing countries. *World Bank policy research working paper 4075*. http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2006/12/05/000016406_20061205151452/Rendered/PDF/wps4075.pdf, accessed on Apr 23, 2009.

Malinvaud, E. (1972): The allocation of individual risks in large markets. *Journal of Economic Theory* 4, 312-328.

Malinvaud, E. (1973): Markets for an exchange economy with individual risks. *Econometrica* 41, 383-410.

Matsuyama, K. (1991): Agriculture productivity, comparative advantage, and economic growth. *Journal of Economic Theory* 58 (2), 317-334

Mookherjee, D. and Png I. (1989): Optimal auditing, insurance and redistribution. *Quarterly Journal of Economics* 103, 399-415.

Munich Re (2009): *Topics Geo Natural catastrophes 2008: analyses, assessments, positions*. Munich: Munich Re Group Knowledge Series. http://www.munichre.com/publications/302-06022_en.pdf, accessed on Jun 28, 2009.

Mürmann, A. (2001): Pricing catastrophe insurance derivatives. Research paper, The Wharton School. http://www.huebnergeneva.org/documents/catastrophederivatives.pdf, accessed on Apr 28, 2009.

Neary, J. P. (1997): R.C. Geary's contributions to economic theory. In D. Conniffe edited, *R.C. Geary, 1893-1983: Irish Statistician*, Oak Tree Press, Dublin.

Non-Life Insurance Rating Organization of Japan (NLIRO) (2008): *Earthquake Insurance in Japan*. http://www.nliro.or.jp/english/earthquake.html, accessed on 29, Sep, 2008.

Oates, W. (1972): *Fiscal Federalism*. Harcourt Brace Jovanovich.

Patrick, G. F. (1988): Mallee wheat farmers' demand for crop and rainfall insurance. *Australian Journal of Agricultural Economics* 32, 37-49.

Persson, T. and Tabellini, G. (1996): Federal fiscal constitutions: risk sharing and redistribution. *Journal of Political Economics* III, 1081-1110.

Picard, P. M. and Zeng, D. Z. (2005): Agriculture sector and industrial agglomeration. *Journal of Development Economics* 77, 75-106.

Preobrazhensky, E. (1965): *The New Economics*. Oxford: Clarendon Press.

Quiggin, J. (1988): A note on the variability of rainfall insurance. *Australian Journal of Agricultural Economics* 30, 63-39.

Rode, D., Fishhoff, B. and Fischbeck, P. (2000): Catastrophic risk and securities design. *Journal of Behavioral Finance* 1 (2), 111-126.

Sah, R. K. and Stiglitz, J. E. (1984): The economics of price scissors. *The Amer. Econ. Rev.* 74 (1), 125-138.

Scawthorn, C. (2006): National insurance programs for natural hazards mitigation. Presentation at *the Sixth IIASA-DPRI Annual Forum on Integrated Disaster Risk Management*, August 13-17, 2006 in Istanbul, Turkey.

Schade, C., Kunreuther, H., Kaas, K. (2002): Low-probability insurance decisions: the role of concern. *Wharton Risk Center Working Paper*, Wharton Business School, University of Pennsylvania, http://edoc.hu-berlin.de/series/sfb-373-papers/2002-23/PDF/23.pdf, accessed on Feb 11, 2008.

Shi, P. (2007): Natural disaster insurance issue and strategy of China. Paper Presented on *the First International Conference on Asia Catastrophe Insurance*, December 3-4, 2007 in Kyoto, Japan.

Siamwalla, A. and Valdes, A. (1986): Should crop insurance be subsidized? In Hazell, P. et al. edited *Crop Insurance for Agriculture Development: Issues and Experiences*. Baltimore and London: the Johns Hopkins University Press, 117-125.

Skees, J. R. (1999): Agricultural Risk Management or Income Enhancement. *Regulation*, 22 (1), 35-43.

Skees, J., Barnett, B. and Hartell, J. (1995): Innovations in government responses to catastrophic risk sharing for agriculture in developing countries. Paper prepared for workshop *Innovations in Agricultural Production Risk Management in Central American: Challenges and Opportunities to Reach the Rural Poor*, Antigua, Guatemala, 1-12 May 2005. http://www.globalagrisk.com/Pubs/2005%20Innovations%20in%20Govt%20Responses%20to%20Catastrophic%20Risk%20jrs%20bjb%20jh.pdf, accessed on April 28, 2009.

Smith, V. H. and Baquet, A. E. (1996): The demand for multiple peril crop insurance: evidence from Montana wheat farms. *Amer. J. Agr. Econ.* 78 (1), 189-201.

State Statistical Bureau of China (2009): Statistical Year Book of China 2009 (online version). http://www.stats.gov.cn/tjsj/ndsj/2008/indexch.htm, accessed on May 20th, 2009.

Statistical Bureau of China (2008): *China Statistical Yearbook 2008*. Available at http://www.stats.gov.cn/tjsj/ndsj/2008/indexch.htm, accessed on July 16, 2009.

Steger, T. M. (2000): Economic growth with subsistence consumption. *Journal of Development Economics* 62, 343-361.

Swiss Reinsurance Company Ltd (2008): Setting up Sustainable Agricultural Insurance: the Example of China. *Focus report of Swiss Re*, available at http://www.swissre.com/pws/research%20publications/risk%20and%20expertise/focus%20reports/agro_china.html, accessed on July 16, 2009.

The People's Government of Hunan Province of China (2008): *The implementation plan of agriculture insurance program in Hunan Province in 2008*. (in Chinese)

The State Council of China (2006): Some opinions of the state council on the reform and development of the insurance industry. http://www.xinhuanet.com, accessed on Nov 17, 2007.

Timmer, C.P. (1992): Agriculture and economic development revisited. *Agricultural Systems* 40, 21-58.

Townsend, R. (1979): Optimal contracts and competitive markets with costly state verification. *Journal of Economic Theory* 21, 1-29.

Tuo, G. and Li, J. (2005): *Agriculture Insurance*. Beijing: Renmin University of China Press. (In Chinese)

Tuo, G. and Wang, G. J. (2002): *A study on Agriculture Insurance and Rural Social Security System of China*. Beijing: Capital University of Economics and Business Press. (In Chinese)

Wildasin, D. E. (1986): *Urban Public Finance*. Chur, London, Paris, New York: Harwood Academic Publishers.

Wildasin, D. E. (1995): Factor mobility, risk, and redistribution in the welfare state. *Scand. J. of Economics* 97 (4), 527-546.

World Bank (2006): *Hazards of nature, risks to development: an IEG evaluation of World Bank assistant for natural disasters*. The World Bank, Washington DC. http://siteresources.worldbank.org/INTEVAOFBASSND/Resources/natural_disasters_evaluation.pdf, accessed on Apr 23, 2009.

Yaari, M. E. (1976): A law of large numbers in the theory of consumer's choice under uncertainty. *Journal of Economic Theory* 12, 202-217.

Yang, D. T. (1997): China's land arrangements and rural labor mobility. *China Economic Review* 8 (2), 101-116.

Yokomatsu, M. (2006): Insurance behavior in developing countries. Paper presented at *the Sixth IIASA-DPRI Annual Forum on Integrated Disaster Risk Management*, Istanbul, Turkey, August 13, 2006.

Yokomatsu, M. (2007): Barriers to insuring against disaster in developing countries. Paper presented at *the Seventh IIASA-DPRI Annual Forum on Integrated Disaster Risk Management*, Stresa, Lago Maggiore, Sept 17, 2007.

Yokomatsu, M. and Kobayashi, K. (2000): Catastrophic risks and economic valuation of disaster mitigation. Paper presented on *the Second Euro Conference on Global Change and Catastrophe Risk Management: Earthquake Risks in Europe*, July 6-9, IIASA, Austria.

Yokomatsu, M., Kobayashi, K. and Tanaka, K. (2001): Decentralized mitigation and regional allocation of disaster risks. *Special collection of presentations, Urban Planning Study* 23 (2), 149-152. (in Japanese)

Yu, W.B. (2008): *Disaster Risk Management in Agricultural Sectors of China with Focus on Complementarity between Revised Institutions and Traditional Functions*. Doctoral thesis of Kyoto University.

Zhao, Y. (1999a): Leaving the countryside: rural-to-urban migration decisions in China. *AEA Papers and Proceedings* 89 (2), 281-286.

Zhao, Y. (1999b): Labor migration and earnings differences: the case of Rural China. *Economic Development and Cultural Change* 47 (4), 767-782.

Innes, R. (2003): Crop Insurance in a political economy: An alternative perspective on agricultural policy. *Amer. J. Agr. Econ.* 85(2), 318-335.

Ye, T., Yokomatsu, M. and Okada, N. (2008): The China Agriculture Policy Insurance Pilot Program: the gap between design and implementation. Presentation at *the third Seminar of Disaster Prevention Planning of Disaster Prevention Research Institute: Regional Disaster Prevention from Various Perspectives*, Oct 25, 2008, Kyoto, Japan.

Zhou, M.Q., Ye, T. and Shi, P.J. (2009): Review and research on crop insurance system of China -- case study in Hunan Province. Poster presentation at *the Asian Conference on Risk Assessment and Management 2009* May 17 19, 2009, Beijing, China.